

Water Use in the Shenandoah Valley of Virginia

1982 - 2010



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Groundwater Characterization Program

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Cover: View near Keezletown of Grubs Knob, part of the Massanutten Range in central Rockingham County, to the northeast.
(Photograph by Joel Maynard, Virginia Department of Environmental Quality, October 2009)

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Abstract

Three decades of reported surface water and groundwater use data were analyzed to identify areas of concentrated withdrawals and to create categorized water use trends for the Shenandoah Valley. In addition, estimated water withdrawals were developed for non-exempt sectors believed to be underreported and other sectors that are exempt from water withdrawal reporting regulations, in order to establish a more complete approximation of total water use in the valley.

Total reported and estimated water use in the study area was calculated to be 38,637 million gallons (MG) or approximately 106 million gallons per day (MGD) in 2007. On average, 53% of all reported water use in the valley was from groundwater sources. Water wells increasingly supply the majority (91% of volume in 2010) of reported groundwater withdrawals in the valley, and have slowly replaced spring withdrawals which have been in decline since 1994. Most water use sectors showed signs of increasing consumption throughout the period of study.

Public water supplies led all other sectors in water use and experienced an approximately 55% increase in the volume of reported withdrawals since the early 1980's. Manufacturing was once the dominant water use sector in the region but has experienced an overall decline in reported water use since 1982. Water withdrawals for uses that are either exempt from reporting requirements such as self-supplied domestic withdrawals and mine dewatering activities or are non-exempt sectors that are believed to be underreported, such as agricultural-livestock watering and crop irrigation, were estimated to represent approximately 1/3rd of the total volume of water use in the study area in 2007. Estimations of self supplied domestic water use showed a steady growth trend similar to the public water supply sector that will soon surpass manufacturing as the second largest water use sector in the valley. Estimations of agricultural and irrigation water demands suggest significant under-reporting of withdrawals by these sectors in the valley and mine dewatering withdrawals estimated in this report are more significant than previously known.

Although constituting less than half of the surface area of the valley, over 95% of reported withdrawals by volume originate from the calcium carbonate rocks of the valley floor. A relatively thin linear concentration of reported groundwater withdrawals was identified in two carbonate rock groupings in eastern Augusta and Rockingham counties that accounted for roughly 54% of the total volume of reported groundwater withdrawals in the valley in 2007. Field and database work targeting facilities that previously had missing groundwater source locations or construction information improved the accuracy of 177 major well or spring sources and resulted in significant changes in projected formation-scale groundwater use statistics.

Water Use in the Shenandoah Valley of Virginia 1982 - 2010

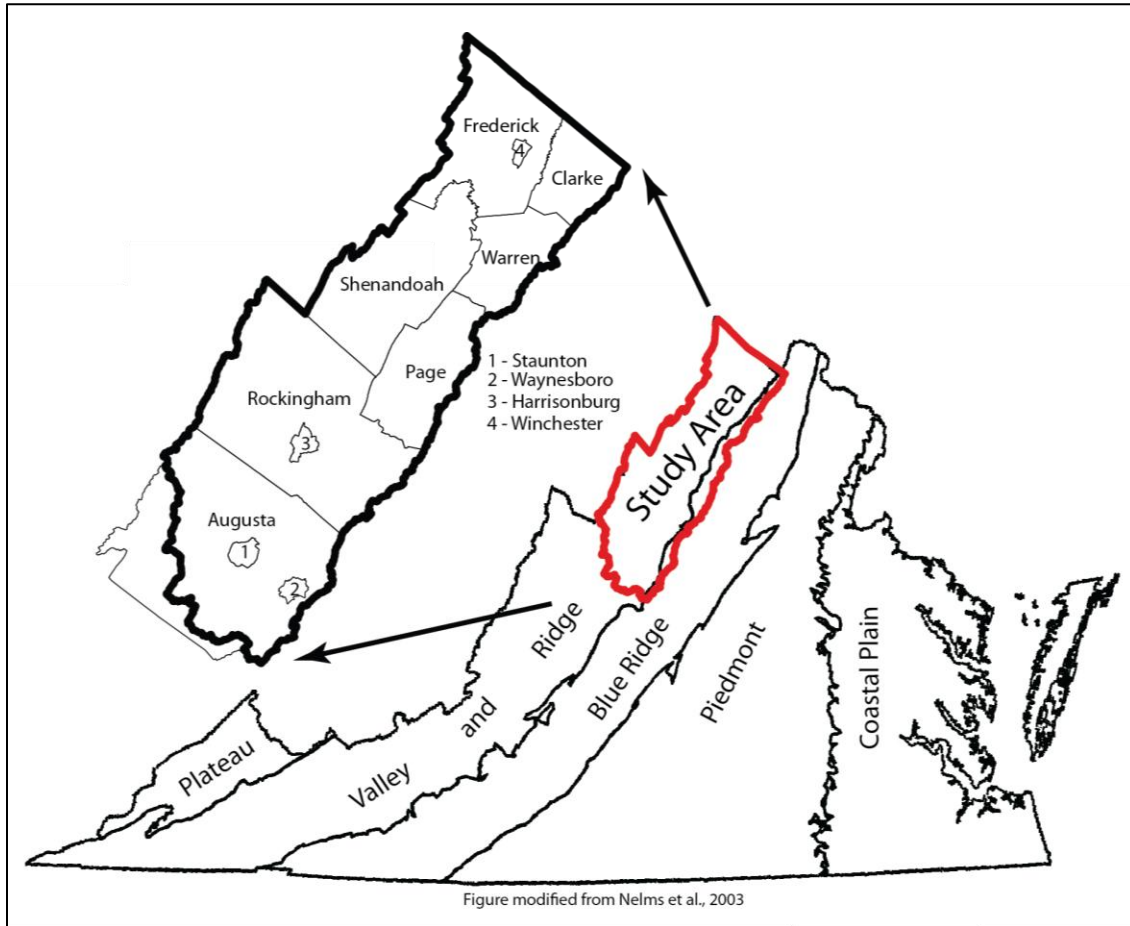


Figure 1: Location of study area

Purpose

Water is the cornerstone of life on Earth, and without it society and life cannot exist. Despite its overwhelming importance throughout our daily lives, much work remains to be done in order to answer many of the most basic questions related to water use, availability and quality in Virginia. The main objectives of this regional study included: gaining an understanding of the volume of water used, how it is used, where it is used, the relative importance of groundwater and surface water sources, and how these and other factors have changed through time. In the

process of trying to meet these objectives, Virginia's statewide water use database was evaluated to understand the level of accuracy and completeness of the dataset locally and to identify areas where improvements could be made. Field work was conducted during this study in order to improve the accuracy of this and subsequent studies on groundwater availability in the region. This report provides the most comprehensive examination of water use in the Shenandoah Valley to date and will hopefully be of value to policy makers and the general public when making future water management decisions in the region.

Area of Study

The Shenandoah Valley is part of the Great Valley section of the central Appalachian Valley and Ridge Province which extends from southern New York to Central Alabama. The Great Valley is bordered to the east by rocks of the Blue Ridge Province and to the west by the Appalachian Plateau. The part of the Great Valley south of the Potomac River in northern Virginia is called the Shenandoah Valley (Yager et al. 2008). The area of study for this report encompasses the Virginia counties of Frederick, Clark, Warren, Page, Shenandoah, Rockingham, and most of Augusta County (Figure 1). The study area is further delineated by the network of creeks and rivers that feed the North and South Forks of the Shenandoah River. These two main tributaries flow to the northeast and combine near Front Royal to form the main stem of the Shenandoah River which empties into the Potomac River at Harpers Ferry, West Virginia. The Opequon, Hogue and Back Creeks in northwestern Frederick County drain directly to the Potomac River (Figure 18).

Reported Water Use

Methodology

Water-use data for this portion of the report was retrieved from the Virginia Water Use Database System (VWUDS) maintained by the Virginia Department of Environmental Quality - Office of Water Supply. The database is populated with data obtained from the Virginia Water Withdrawal Reporting Regulation (VAC 25-200-10 et seq.) and contains monthly water-use information for individuals or facilities whose average daily withdrawal during any single month exceeds 10,000 gallons per day. A reporting threshold for crop irrigators (including turf farms and nurseries) is established for withdrawals exceeding 1,000,000 gallons in any single month. Monthly withdrawals are self-reported annually by system owners and encompass captured water that is used directly

by the system owner, released locally to customers of the system, or transferred to other systems. Withdrawal reports are classified by type (surface water or groundwater), sub-type (springs, wells, streams / rivers, and reservoirs), and sector (Agricultural, Commercial, Irrigation, Manufacturing, Mining, Public Water Supplies, Fossil Power, Hydropower, and Nuclear Power). Four hydropower facilities reported surface water withdrawals in the Shenandoah Valley from 1982 until 2006 but were not included in this analysis because they were non-consumptive “run of the river” conventional operations where withdrawals equaled releases in the same month.

Water-use is believed to be underreported in some areas of the state, mostly from smaller system owners. Underreporting of withdrawals can be attributed to a lack of awareness of the law and insufficient resources available to monitor and enforce the Virginia Water Withdrawal Reporting Regulation. County-scale, quinquennial water use data published by the U.S. Geological Survey were compiled for the study area and compared with values obtained independently during this study. At the time of this study, data for 2010 had not yet been published by the USGS.

Groundwater withdrawals from the VWUDS dataset were analyzed in greater detail to evaluate locational accuracy of measuring points (MPIDs). This was done to ensure a degree of accuracy in geospatial analysis of groundwater withdrawals at the end of this report. MPIDs typically identify and locate individual surface water and groundwater withdrawal points such as a well, spring, or river, but are sometimes used to identify a central metering location for several sources. Initial analysis showed that 287 measuring points (MPIDs) had reported groundwater use in the study area at one time or another during the period of 1982 to 2007. Thirty-six (36) of those MPIDs were missing latitude or longitude and several more had locations that were obviously wrong or incorrectly categorized. It was determined that less than half of the MPIDs (135 out of 287) had any associated well construction

information (driller's reports, yield and drawdown tests, water quality information) on file in VDEQ's Statewide Water Well Construction Database. Although not essential to this report, well construction information is the cornerstone of regional hydro-geologic analysis and capturing well data from these major groundwater sources was considered essential to improving the accuracy of future studies on groundwater availability in the region.

Starting in the spring of 2010 and continuing until the end of 2011, an effort was made to improve the accuracy of the VWUDS dataset in the Shenandoah Valley. Field inspections and data research were conducted on approximately 60 systems that had one or more MPIDs with missing locational or well construction information. Missing information could sometimes be deduced through GIS-based correlation with the Virginia State Well Construction Database or through file research at local and state health departments. Sometimes information could be obtained from system operators and/or private well drillers. Several times however, a full system inspection and occasionally even geophysical logging was necessary to clarify naming confusion and well construction details.

Update of the VWUDS database in conjunction with the state well construction database resulted in significant improvement of data accuracy and cross-correlation in both datasets. An analysis of the VWUDS dataset following field and database work showed that 177 groundwater MPIDs (wells and springs) were located with post-processed, sub-meter accuracy GPS and that 276 of the 314 MPIDs that had reported groundwater use at some time between 1982 – 2010 now had associated construction information. Several categorization errors were also corrected such as springs that were incorrectly categorized as surface water or groundwater sources that were attributed to the incorrect surface water basin or use sector. Additionally, a handful of new MPIDs were discovered to have been put into service at some facilities but had not been reported to DEQ as

well as some instances where the operator forgot to report water use from existing MPIDs after VDEQ started electronic self-reporting of withdrawals in 2008. Increased locational accuracy had significant impacts to formation-scale water use statistics due to the fact that most geologic units in the valley are relatively thin, pseudo-linear bodies where a seemingly small change in location sometimes resulted in a well that plotted in a different geologic unit (Table 9).

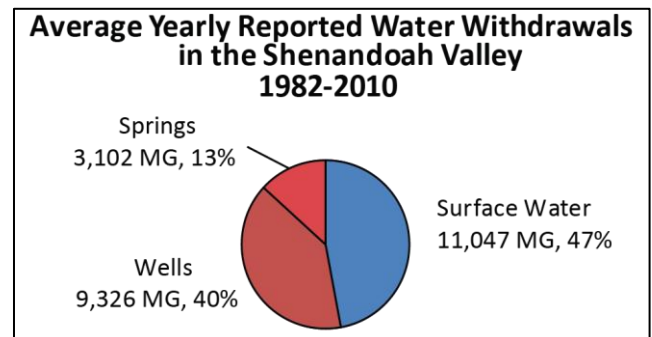


Figure 2. Average yearly reported withdrawals of surface and groundwater in the Shenandoah Valley from 1982 to 2010.

Total Reported Water Use

From 1982 to 2010, reported withdrawals of both surface and groundwater from the Shenandoah Valley averaged a combined total of 23,477 million gallons (MG) per year. Approximately 53% or 12,430 MG per year was from groundwater sources such as wells or springs (Figure 2). Total water withdrawals decreased from a high of 27,893 MG in 1982 to a low of 19,476 MG in 1991 and has increased since that time to approximately 24,387 MG in 2010 (Figure 3, Table 1).

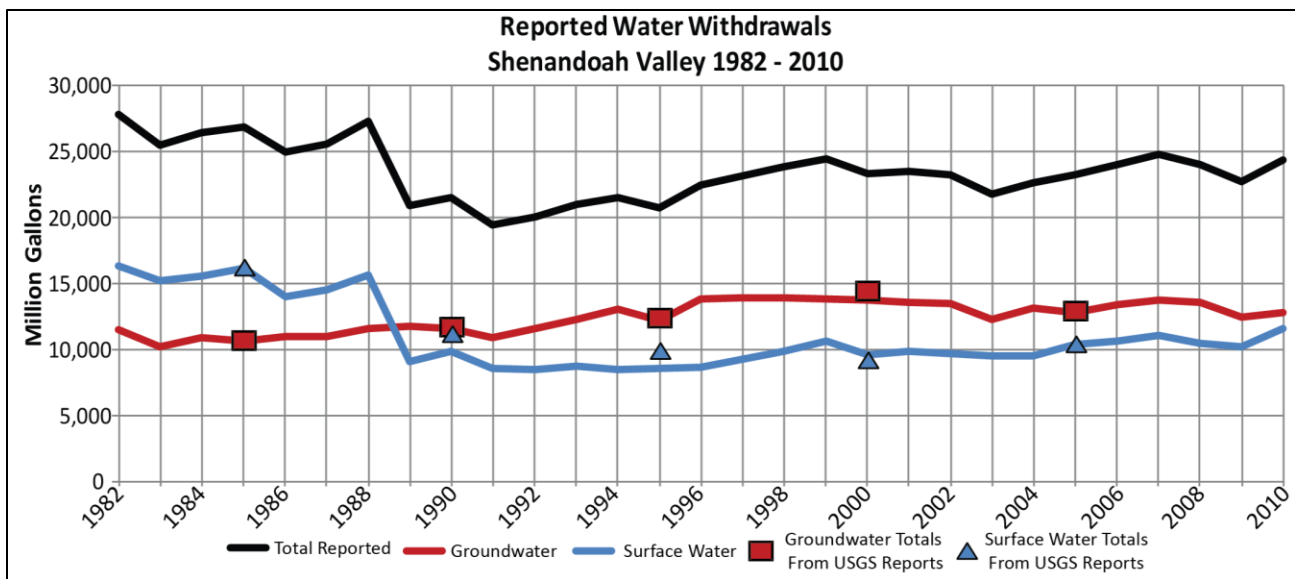


Figure 3. Reported surface water and groundwater withdrawals in the Shenandoah Valley from 1982 to 2010. * USGS data compiled from county level water use reports (USGS, 1990; USGS, 1995; USGS, 2000; USGS, 2005)

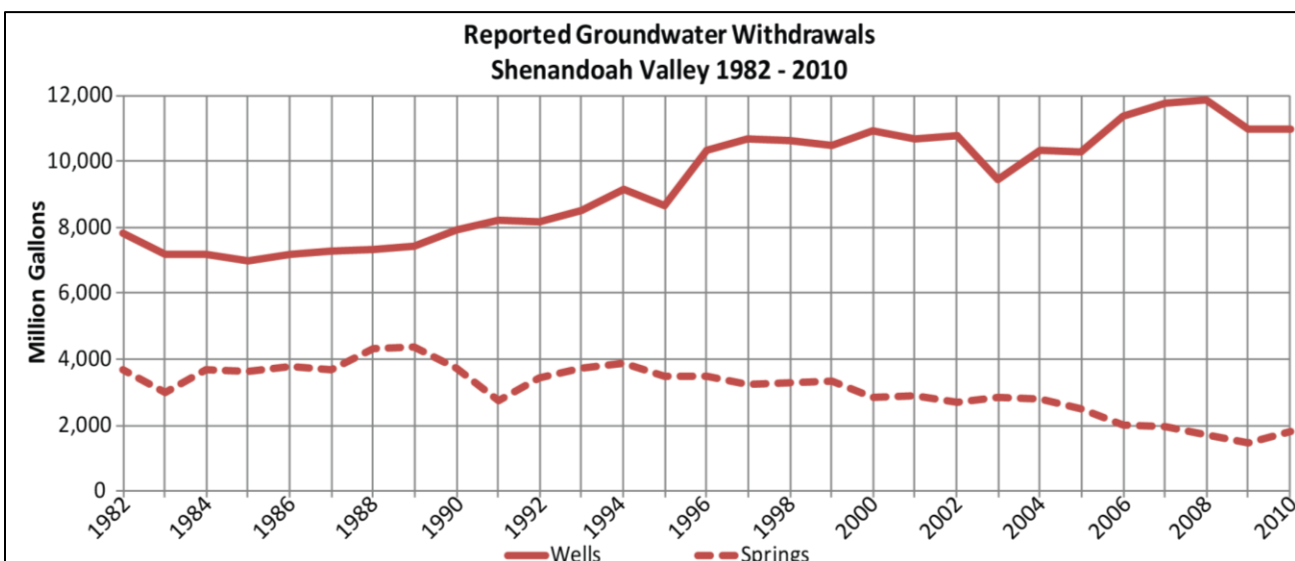


Figure 4. Reported groundwater withdrawals by type in the Shenandoah Valley for the period of 1982 – 2010.

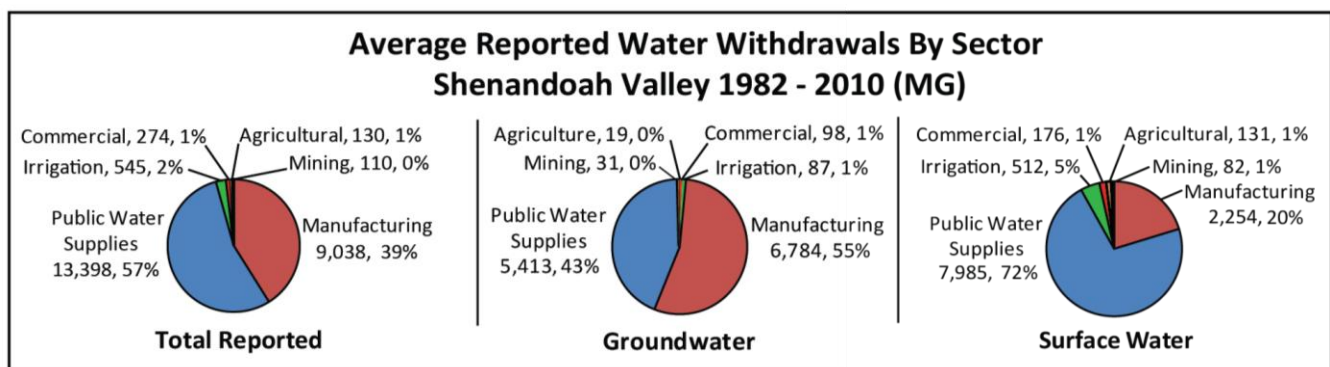


Figure 5. Average reported water withdrawals by sector for the Shenandoah Valley 1982 to 2010.

Reported groundwater use in the Shenandoah Valley increased approximately 36% from a 1983 low of 10,195 MG to a high of 13,921 MG in 1998. Reported groundwater withdrawal rates decreased slightly since 1998 to a reported withdrawal of 12,801 MG in 2010 (Figure 3, Table 1). Reported surface water use decreased almost 48% from a high of 16,357 MG in 1982 to 8,456 MG in 1992, a precipitous decline attributable to a decrease in the use of surface water sources by the manufacturing sector. Reported surface water use has rebounded since 1992 to 11,585 MG in 2010.

Water wells increasingly supply the vast majority of groundwater to reporting water users in the Shenandoah Valley (Figure 4, Table 1). Since 1982, the average well withdrawal rate has been 9,327 MG per year and currently accounts for approximately 91% of reported groundwater withdrawals in the valley. The yearly rate of withdrawals from water wells increased approximately 55%, from a low of 7,006 MG in 1985 to a high of 11,846 MG in 2008. Reported spring use averaged 3,103 MG for the past 29 years. Peak spring water use of 4,361 MG was

reported in 1989 but was followed by a gradual decline to a period minimum of 1,800 MG in 2010, a decline of approximately 59%.

Reported Water Use by Sector

Manufacturing and Public Water Supply sectors account for the vast majority of both groundwater and surface water withdrawals reported in the Shenandoah Valley (Figure 5). On average, withdrawals for manufacturing purposes accounted for 55% of all reported groundwater but only 20% of all surface water used in the valley. Public water supply use accounted for roughly 43% of reported groundwater use but over 72% surface water use in the region. Total water use by the public water supply sector has experienced an overall growth at the same time that total water use by the manufacturing sector experienced long-term decline (Figure 6, Tables 2 & 3). In 1989, reported water withdrawals by Public Water Supplies surpassed total withdrawals reported by the Manufacturing sector in the Shenandoah Valley.

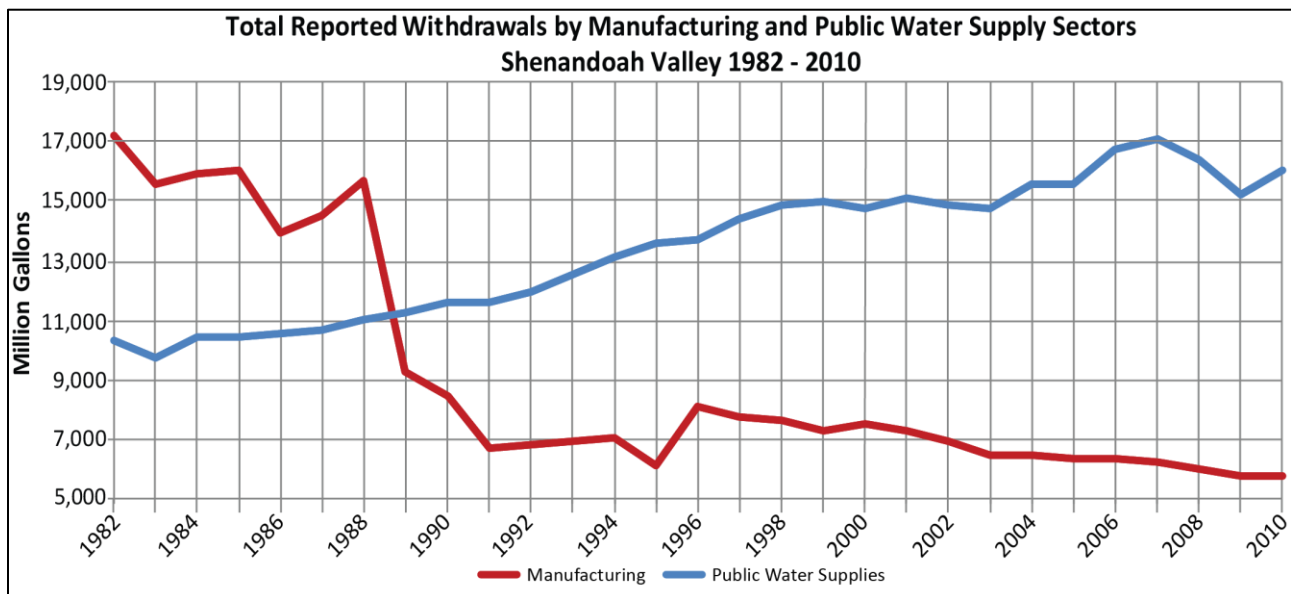


Figure 6: Reported water withdrawals by the Manufacturing and Public Water Supply sectors in the Shenandoah Valley for the period of 1982 to 2010.

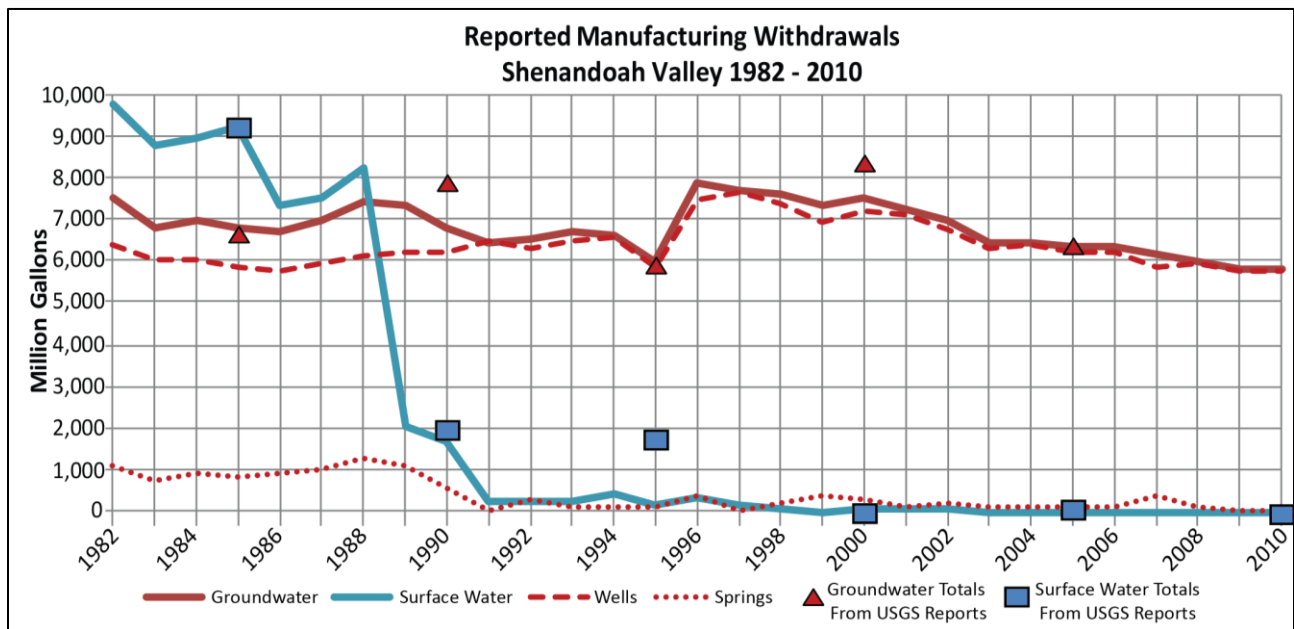


Figure 7. Reported water withdrawals by the Manufacturing sector in the Shenandoah Valley.

Manufacturing

Groundwater has been the dominant type of water withdrawal reported by the manufacturing sector since 1989. An average of 6,784 million gallons per year, or roughly 55% of all groundwater reportedly used in the Shenandoah River watershed is used for manufacturing purposes (Figures 5 & 7, Table 3). A precipitous decline in surface water use by this sector occurred following the closing of the Avtex plant in Front Royal in the late 1980s.

The vast majority of manufacturing withdrawals of groundwater in the watershed are from supply wells. Peak groundwater use of 7,832 MG was reported by the manufacturing sector in 1996. Reported groundwater use by the manufacturing sector in the valley has declined approximately 26% since 1996 to a reported use of 5,788 MG in 2010. The gradual decline in water use by this sector is attributable to closures of some facilities throughout the period of record but also driven in part by an increase in the efficient use of process water.

Public Water Supply

Use of both surface and groundwater by public utilities has increased approximately 55%

since 1982, becoming the dominant use sector in 1989 (Figures 6 & 8, Table 2). Total reported withdrawals by this sector grew from 10,270 MG in 1982 to 15,978 MG in 2010. Groundwater sources (specifically wells) have been increasingly utilized to meet growing demand but surface water sources still accounted for approximately 58% of reported public utility withdrawals in 2010. Reported groundwater use increased 120% from 3,307 MG in 1983 to a high of 7,276 MG in 2008, an average increase of approximately 4% per year.

Springs supplied over half of the groundwater withdrawals reported by public utilities in the Valley until 1998. Peak spring use by this sector was 3,680 MG in 1994. Since that time, public water supplies have increased reliance on wells, while spring use has declined. The decreased reliance on springs is not due to decreased availability of discharge from springs but appears to coincide with the regulatory designation of many springs as “groundwater under the direct influence of surface water”. State legislation was passed in 1993 (12VAC5-590-430) that required the evaluation of surface water influence of all groundwater sources in limestone bedrock terrain which is common in the valley (Figure 21). Many spring sources

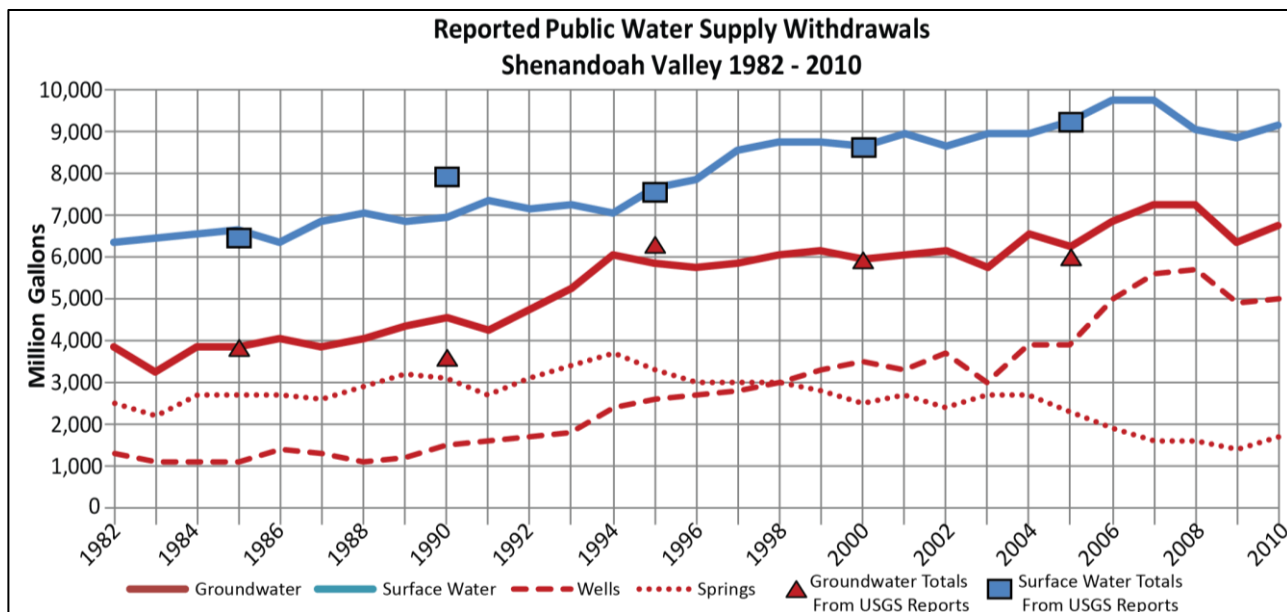


Figure 8. Reported water withdrawals by the Public Water Supply sector in the Shenandoah Valley.

(and some wells) utilized by waterworks were determined to be directly influenced by surface water, requiring increased treatment costs. Some utility operators successfully drilled supply wells constructed to exclude surface water-influence in order to save on increased annual treatment costs.

Other Sectors

Reported withdrawals from other sectors (Commercial, Irrigation, Mining, and Agriculture) were minor when compared to the use reported from the manufacturing and public water supply sectors in the valley. The combined withdrawals from these sectors in 2010 was 2,610 MG, or roughly 10% of the reported use in the Shenandoah Valley (Figures 5 & 9, Table 4). Commercial sector withdrawals averaged 274 MG per year, were mostly from groundwater sources and exhibited no overall growth trend. Golf course irrigation, various hotels and a few resorts make up the majority of commercial sector systems that report use in the valley. Reported water withdrawals from irrigation, mining, and agriculture sectors are variable with no overall trends and believed to be underreported, especially when the ubiquity and economic significance of these sectors in the region is considered (Figure 12). Mining dewatering

activities are excluded from the water use reporting regulation so true water use by the mining sector is known to be significantly higher than reported. Water withdrawal estimations for agricultural and irrigation sectors, and mining dewatering activities by quarries, are presented in the “Estimated Water Use” section later in the report. These estimations are combined with self-supplied domestic estimations to provide a better picture of total water use in the region.

Reported Water Withdrawals by Owner

In 2010, ten (10) system owners represented approximately 68% (16,513 MG) of reported water withdrawals in the Shenandoah Valley (Figure 10, Appendix 1). In 2010, Merck was the largest user of water in the Shenandoah Valley pumping 3,107 MG of groundwater from its production wells in eastern Rockingham County to manufacture pharmaceutical products. Although being the largest user of water in the valley, the facility has actually decreased its withdrawals of groundwater approximately 16% from volumes reported in the early 1980s. This trend is supported by facility operators at Merck who report that increased efficiencies in industrial scale water use at the facility have decreased pumping needs to the point where some of their 12 production wells now sit idle much of the time (Helen Penrod, pers comm.). The only other manufacturing sector facility that

approached Merck's volume of withdrawals was Invista in eastern Augusta County (1,207 MG). Invista also reported decreasing groundwater withdrawals since the early 1980s. O-N Minerals Company in Shenandoah County, reported mining withdrawals totaling 1,008 MG in 2010. The rest of the top ten water users for 2010 were public water supplies for the major cities and towns in the region.

This examination of water withdrawals by owner does not take into account transferred water – water that is withdrawn by one system owner but sold to or bought from other system

owners or localities. Water transfers in the region are not entirely uncommon, therefore withdrawal values reported by a system owner might not always equate to the actual water used by that facility or locality in any given year. There were 25 water transfers reported in the Shenandoah Valley in 2010, but examination of transfer data indicates that better accounting of water bought and sold between system owners is needed in order to fully account for water use by system owners.

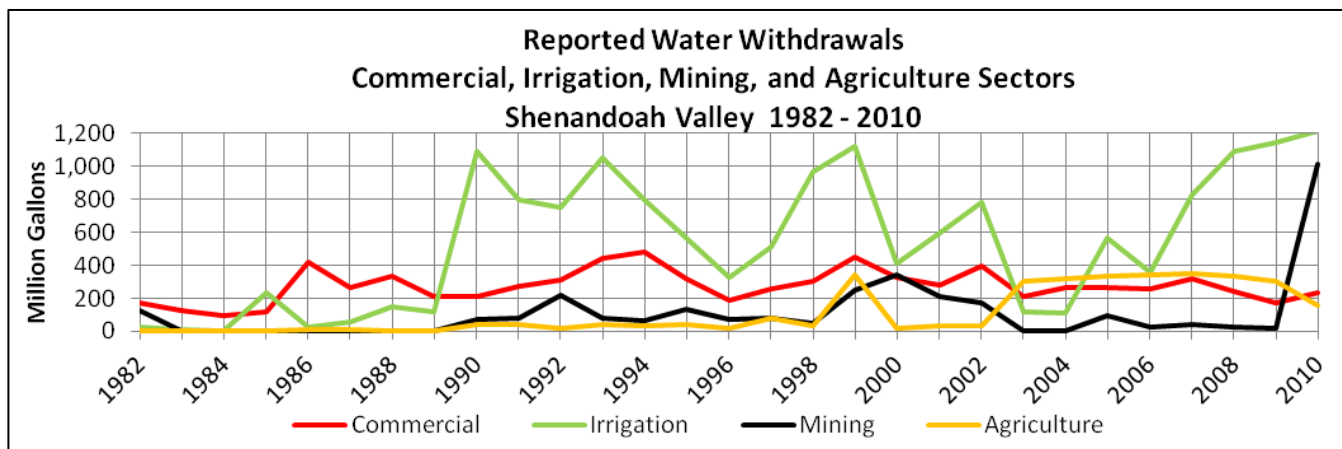


Figure 9: Reported water withdrawals by the Commercial, Irrigation, Agriculture and Mining sectors in the Shenandoah Valley for the period of 1982 to 2010.

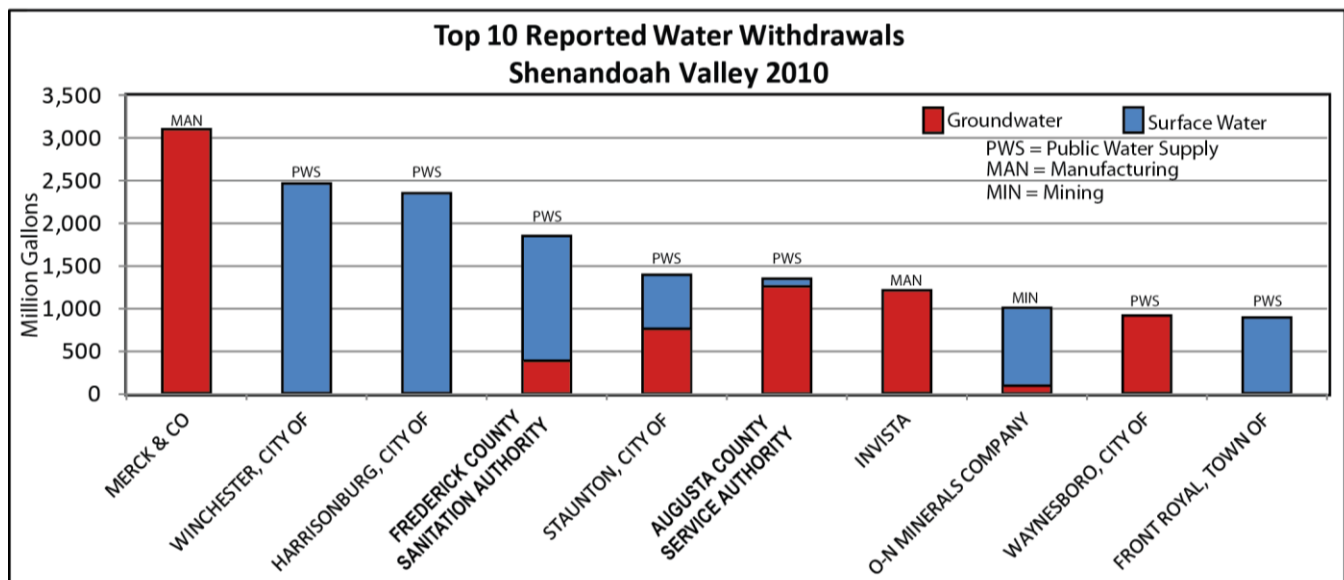


Figure 10: The top 10 reported water withdrawals in the Shenandoah Valley in 2010.

Estimated Water Use

Estimation of Self Supplied Domestic Water Use

Self-supplied domestic water use includes withdrawals of water from wells, springs and streams for normal household purposes. Common indoor uses include drinking, preparing food, bathing, washing dishes and clothes, and flushing toilets. Major outdoor uses include watering lawns, gardens and shrubbery (Hutson et al, 2004). Self-supplied domestic water use is not tracked by any government entity and must be estimated. A common assumption is that the majority (>98%) of self-supplied domestic withdrawals are from groundwater sources due to sanitary considerations of using untreated surface water (Atkins, 2007). In light of the uncertainties inherent with estimations, values calculated in this section should be viewed as first order approximations used to compare the relative magnitudes of the distributed domestic demand to that of reporting groundwater users.

Methodology

The estimation method used in this report involved the multiplication of a per capita water use coefficient by the estimated self-supplied population for a county or city. Estimations of the self-supplied population were obtained from the 1990 U.S. Census (U.S. Bureau of the Census, 1992). The 1990 census was the only time during the past 29 years that the U.S. Census collected data on the percentage of a county or city's population that obtained water from municipal or commercial sources. These values were multiplied by annual population values of the county or city to obtain county-scale estimates of the self-supplied domestic population (U.S. Bureau of the Census, 2002; U.S. Bureau of the Census, 2008; U.S. Bureau of the Census, 2010) (Appendix 2a). The self-supplied domestic population estimate was then multiplied by an average domestic water use coefficient. Nationally, per capita water use

coefficients generally ranged from 60 to 120 gallons/day per person and are derived using public-supply delivery data, or published values in technical literature (Solley et al.1998),(Hutson et al., 2004). The water use coefficient believed to be most representative for the Shenandoah Valley region was 80 gallons/day per person, in agreement with the value used in self-supplied domestic estimations published for West Virginia (Atkins, 2004). Estimations were also performed using the higher and lower range of possible water use coefficients for comparison purposes. The equation used to calculate self-supplied domestic water use (*D*) in this report is:

$$D = 365 (P - P m)W$$

where *P* is county population, *m* is % of population served by municipal systems, and *W* is the water use coefficient. For example, in 2005 the population (*P*) of Shenandoah County was reported to be 39,406 people, with 47.4% of the population served by Municipal water (*m*) (Appendix 2a & 2b). Using a water use coefficient (*W*) of 80 gallons/day per person yields an estimated 2005 self-supplied water use of 605 MG.

The 1990 U.S. Census data on percentage of population served by municipal water was used to estimate self-supplied populations for the years 1990 – 2010 since it was the only Census to collect such data. The percentage of self-supplied and municipal-supplied water users throughout most counties has undoubtedly changed since 1990 as public services have expanded into areas previously serviced exclusively by self-supplied water systems, but the cumulative change is assumed to not be significant for the purposes of this report. The estimation equation was only carried out for the years 1990 – 2010 because no county level population data could be obtained for the years 1982-1989. An assumption was made that the majority of self-supplied users in a region obtained water from groundwater sources such as private wells or springs. This assumption introduces error if residential water is sourced

from rivers or supplied by cisterns filled by private water haulers. Out of necessity, self-supplied domestic water use estimates were performed using county-wide census data and therefore do not exactly match the extent of the Shenandoah Valley area of study. An attempt was made to use voting district population estimates to further delineate self-supplied population centers but was abandoned because the voting district boundaries were found to have changed throughout the period of study. The use of county scale census data means that all of Augusta County, including a portion that drains to the James River (Figure 1), is included in the census estimation method.

Results

Estimations formulated in this report suggest that unreported self-supplied domestic water withdrawals may currently be the second

largest water use sector in the Shenandoah Valley. Water use for this sector appears to be increasing as population continues to rise in the valley, growing from 4,178 MG in 1990 to 5,788 MG in 2010 (using a water use coefficient of 80 gallons/day/person), tying it with manufacturing as the second largest use sector in the valley in 2010 and surpassing the reported water use of the commercial, irrigation, agriculture and mining sectors combined (Figure 11, Table 5). Changing the water use coefficient has a substantial effect on the results. Calculations using the extreme upper and lower range of water use coefficients reported nationally (120 – 60 gallons/day/person (Solley et al. 1998),(Hutson et al., 2004)) would cause estimated water use by this sector to range from an 8,682 MG to 4,341 MG in 2010 (Figure 11).

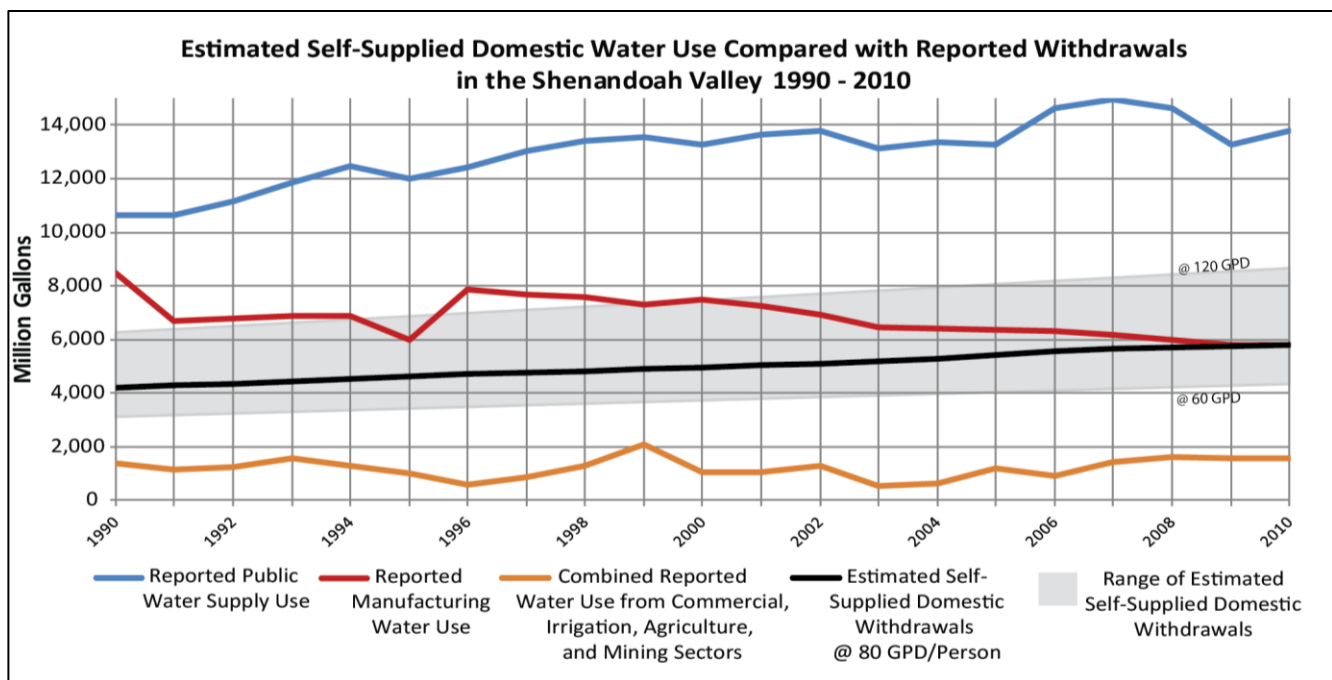


Figure 11: Comparison of estimated self-supplied residential water withdrawals to reported water withdrawals in the Shenandoah Valley 1990-2010.

Estimation of Agricultural Livestock Water Use

Agricultural livestock water use includes groundwater and surface water that is used in feedlots, dairy operations, and for other on-farm

needs. The water may be used for drinking, cooling, sanitation, waste disposal, and other needs related to animal husbandry (Hutson et al., 2004). Sources of water for livestock include surface streams, spring and ponds available in the livestock environment. Additional drinking water is obtained through the animals feed and

pumping of well water into watering stations or ponds on the farm.

Livestock water use is known to be underreported or unreported in most of the United States and must therefore be estimated using gallons-per-head water use coefficients and livestock population estimates rather than actual measurements of withdrawals (Lovelace, 2009).

Drinking water use coefficients vary according to type of livestock, daily temperatures, and amount of water in feed. Water is also needed to meet non-drinking demands which include cleanup, waste disposal, cooling and other needs related to animal husbandry. Water use for non-drinking purposes is highly variable due to the many number of methods used for waste disposal, sanitation and cooling (Lovelace, 2009).

Measurement of water use for livestock would be difficult at many farms as cattle often drink directly out of streams, creeks, and springs in the region. However it may be easier in the future to locally calibrate livestock water use data as more farmers are encouraged to isolate cattle from surface water sources due to water quality considerations.

In the VWUDS database, withdrawals for livestock watering are reported under the category “Agriculture”. Analysis of the database shows that in 2010, only 95 MG of surface water withdrawals and 61 MG of groundwater withdrawals were reported for agricultural purposes in the Shenandoah Valley study area. These reported values appear to be low considering the economic importance of agriculture in the region (Figure 12).

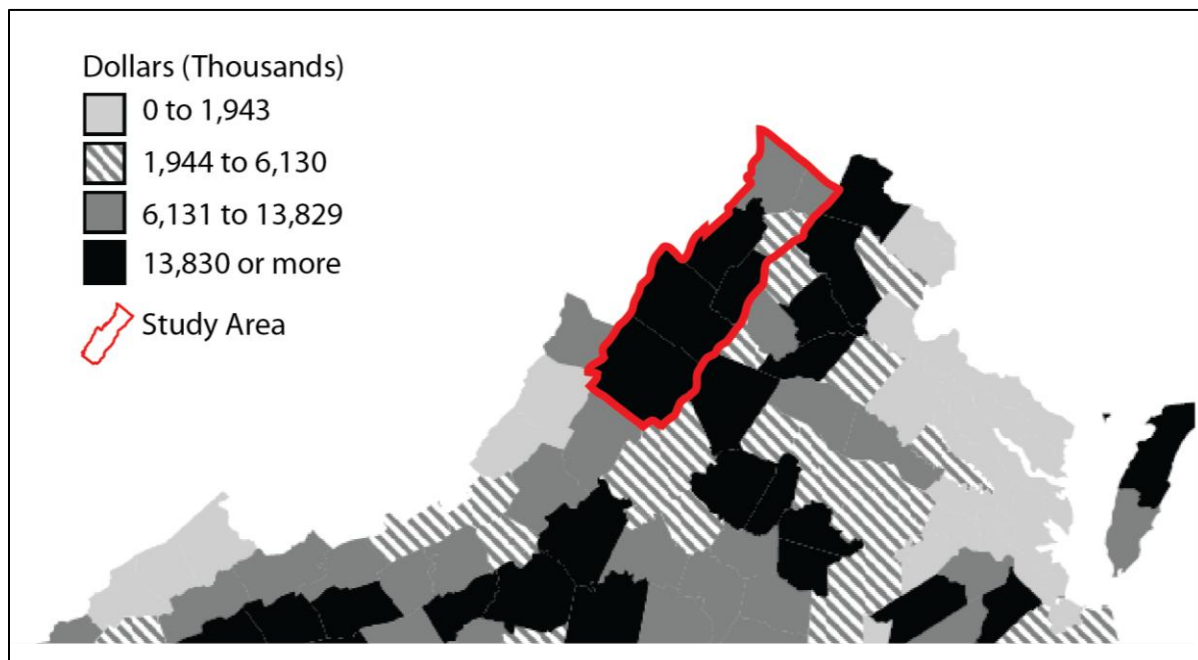


Figure 12: Value of Livestock, Poultry, and their products sold by County (Figure modified from National Agricultural Statistics Service, 1997).

Methodology

In this report, estimates of water use were developed for the major livestock present in the study area by county: beef and other cattle, dairy cattle, swine, turkey, and chickens (including layers, broilers and pullets). No water use

estimations were performed for sheep and lambs, goats, horses, other animals raised for commercial purposes, or fish and other aquatic animals due to the relatively small numbers of these livestock reported in the study area.

Livestock water use was estimated by multiplying the population of livestock reported

to be in each county by a water use coefficient specific to each type of animal. Establishing a ratio of groundwater versus surface water use for watering livestock was not attempted due to the variety of sources and watering methods used, and a lack of data about livestock watering practices in the region. County livestock population estimates were obtained from the United States Department of Agriculture's National Agricultural Statistics Service (NASS). The census of agriculture is the leading source of facts and statistics about the Nation's agricultural production and provides a detailed picture of

U.S. farms and ranches every five years (NASS, 2009). Water use coefficients were developed by averaging published rates with rates obtained from local extension offices and DEQ's agricultural program (Appendix 3b). At the time of writing the 2012 agricultural census was not available, therefore, all agricultural and irrigation estimates were performed for the period 1982 – 2007. Quinquennial population estimates for cattle, swine, and poultry by county in the Shenandoah Valley are presented in Appendix 3a.

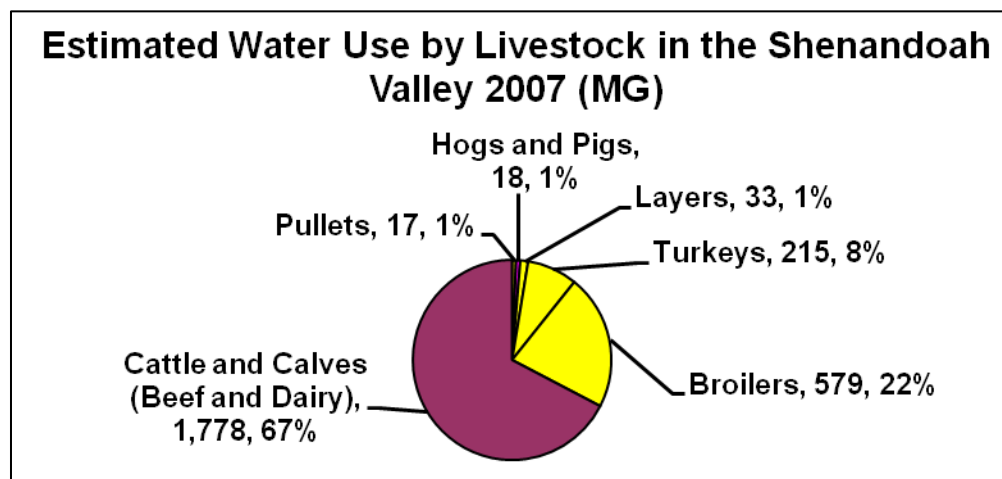


Figure 13: Estimated water withdrawals for livestock, by type in the Shenandoah Valley in 2007.

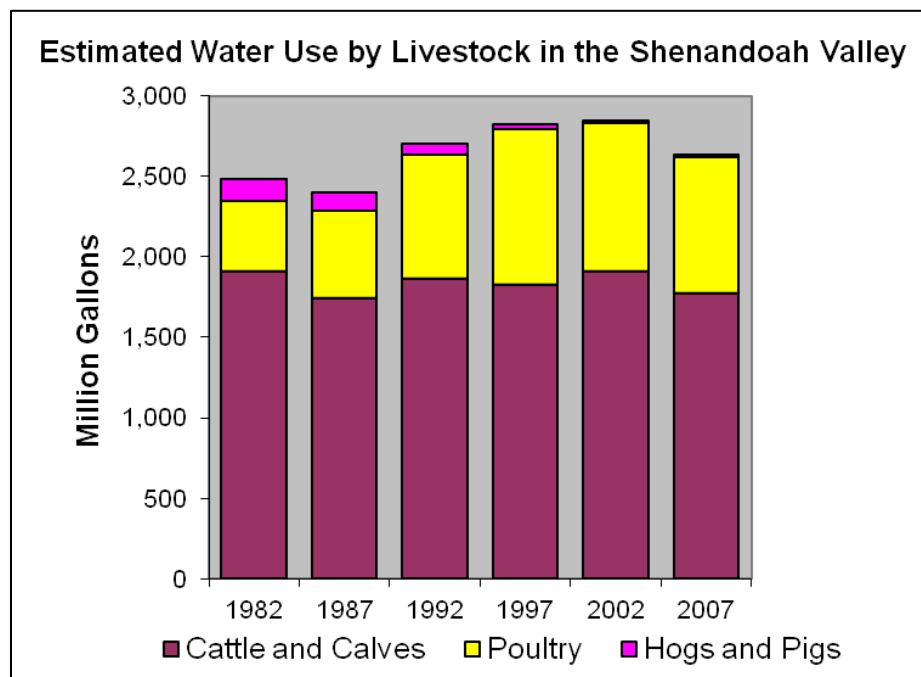


Figure 14: Estimated quinquennial water withdrawals by various livestock types in the Shenandoah Valley.

Results

The estimates calculated in this report suggest that agricultural water use is highly under-reported in the study area. In 2007, the estimated water use for this sector (2,639 MG) was almost 8 times greater than reported (346 MG). Approximately two-thirds of livestock water use was estimated to be for beef and dairy cattle (1,778 MG, 67%) (Figure 13). Little variation is noted in estimated beef and dairy cattle water use since 1982. Poultry was the only type of livestock estimated to have increased water use since 1982. Water use by hogs and swine decreased through time to a relatively insignificant volume (Figure 14, Table 6). Total livestock water use has remained relatively steady since 1982 but reached a peak in 2002 of 2,848 MG. No attempt was made to estimate the relative dependence on groundwater or surface water sources for this sector as no published studies were available documenting such trends in the region.

Estimation of Agricultural Irrigation Water Use

Irrigation has been employed by humans for thousands of years to supplement natural rainfall in order to increase productivity of cropland. In the last few decades, irrigation methods have also gained in popularity as a method to keep lawns and decorative shrubbery green throughout the summer months. Agricultural irrigation is defined as the artificial application of water to the soil in order to increase cropland productivity. Reporting is required by agricultural irrigators if their total water withdrawal for any month exceeds 1,000,000 gallons. Non-agricultural irrigation is the land application of water in order to maintain landscaping and lawns at golf courses, resorts, or private residences. Golf course irrigation is supposed to be reported as a commercial sector withdrawal if water use exceeds 300,000 gallons per month. In this report, estimation of irrigation withdrawals was targeted at agricultural irrigators in order to approximate the degree of underreporting by the sector. Additional studies

would be necessary to provide basic statistics necessary to estimate the degree of underreporting of non-agricultural irrigation throughout the Shenandoah Valley.

Methodology

The amount of water that is needed for irrigation purposes is highly variable and is affected by many factors such as: length of growing season, crop type, crop rotation schedules, evaporation, air temperature, soil temperature, precipitation, soil type, and root zone soil moisture storage as well as economic factors such as fuel and crop price.

In this report, a first-order estimation of agricultural irrigation water withdrawals was performed by using readily available agricultural census data coupled with historical precipitation records. Total agricultural irrigation water use (*I*) was estimated by multiplication of a calculated weekly water deficit (gallons per acre) by the acreage of land reportedly irrigated for that year according to the following equation:

$$I = 27152.187 (1 - X) Y$$

Where (*X*) is the total precipitation in inches recorded during a 7-day consecutive period, (*Y*) is the total area of land reportedly irrigated in the Shenandoah Valley (in acres) for that growing season, multiplied by a unit conversion factor.

The weekly water deficit was defined as any week during the growing season in which less than 1" of precipitation was recorded in the study area. For any week during which 1" or more of precipitation was recorded the assumption was made that no additional irrigation water withdrawals were made. The growing season was defined as the interval of time during the year during which crops can be grown. Elevation, temperature, precipitation, crop selection and earth latitude are all factors which affect the extent of a growing season in a particular region but in general it is constrained by the last frost of the spring and the first frost of the fall. In the Shenandoah Valley, the last frost of spring has historically ranged between mid-

April to mid-May (UVA Climatology Office, 2012). The first frost of fall historically occurs between September 15th and October 1st in western Virginia (NOAA, 2012). In this report the growing season was conservatively defined as the period of April 1st to September 30th.

Depending on the type of crop grown and its growth stage, water requirements may vary from 1" every 5 days to 1" every 14 days. During periods of extreme heat, crops may

require up to 1.5" of precipitation equivalent per week (Kemble and Sanders, 2000). A threshold value of 1" of precipitation equivalent in 7 days was chosen as a median value that best represented crops grown in the Shenandoah Valley and is a value used by the Virginia Department of Environmental Quality's Water Division when evaluating irrigation permits in Virginia's groundwater management areas (Smith, P. pers comm. 28 September 2009).

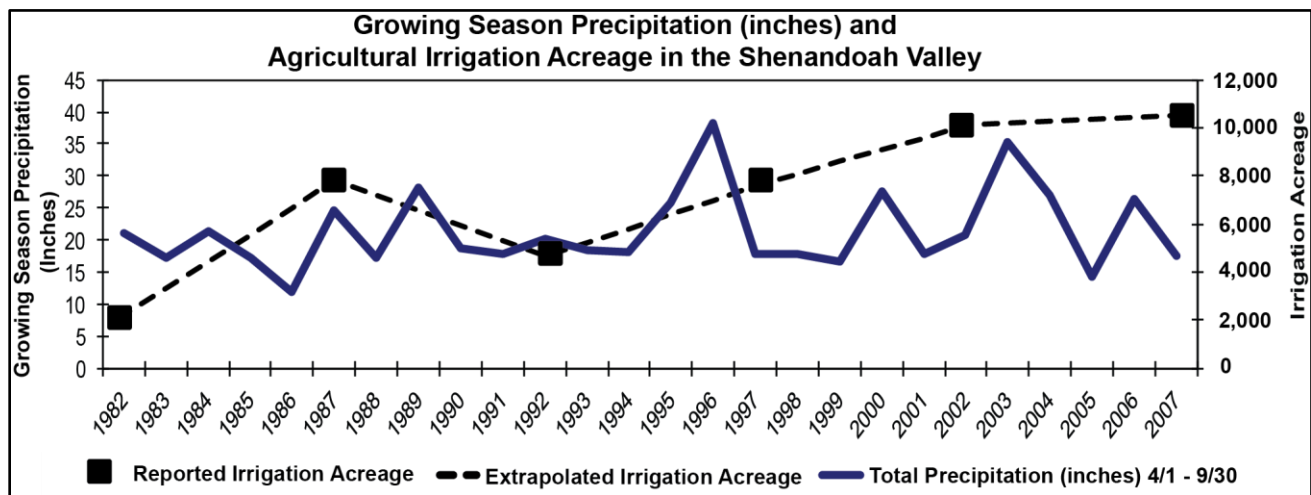


Figure 15: Irrigated acreage and yearly growing season precipitation in the Shenandoah Valley.

The water deficit calculation was performed by summing weekly totals from 25 years of daily precipitation records available for the Dale Enterprise NOAA station (NOAA, 2009). The Dale Enterprise station was chosen due to its long period of record (1948 – current) and its location in Rockingham County which historically has the highest reported irrigation acreage. Accuracy of future estimations could be increased by calibrating use to multiple stations throughout the study area. If the weekly precipitation at the observation site totaled more than 1", a soil water surplus was assumed and the assumption was made that no irrigation water was applied in the entire study area. If the weekly precipitation totaled less than 1", a soil moisture deficit was assumed. In such a scenario, the assumption was that irrigation would be applied from either surface or groundwater sources to make up for that week's water deficit, no attempt was made to

differentiate between groundwater and surface water sources in this simplified estimation although anecdotally crop irrigation is believed to be dominantly sourced by surface water withdrawals. It is not uncommon to see temporary piping and tractor- or diesel-powered pumps running next to streams and rivers throughout the valley during the summer months.

Since 1840, the federal government (U.S. Bureau of Census and later USDA National Agricultural Statistics Service) has collected decennial and later quinquennial agricultural data. Irrigated land acreage was extracted from county level quinquennial datasets for the years 1982, 1987, 1992, 1997, 2002, and 2007. The 2012 agricultural datasets were not available at the time of this report. Irrigated land includes all land watered by any artificial or controlled means, such as sprinklers, flooding, furrows or

ditches, sub-irrigation, and spreader dikes (NASS, 1999). Reported quinquennial irrigated acreage was totaled for counties in the study area and later extrapolated between reported years to match the continuous climatic dataset. The reported and extrapolated agricultural land irrigation acreage values were multiplied by the water deficit calculation to produce an estimated volume of artificial irrigation withdrawals within the study area for each year.

For example, in 1997, only 17.92 inches of precipitation was recorded at the Dale Enterprise NOAA station from April 1st – September 30th. Weekly precipitation totals for the 26 weeks in that period averaged 0.69” and ranged from 0” to 3.35”. Agricultural statistics data for that year reported 7,557 acres of land in the Shenandoah Valley received artificial irrigation. Applying the above equation to each of the 26 weekly precipitation deficit totals yielded a total estimated agricultural irrigation water use of 2,877 MG.

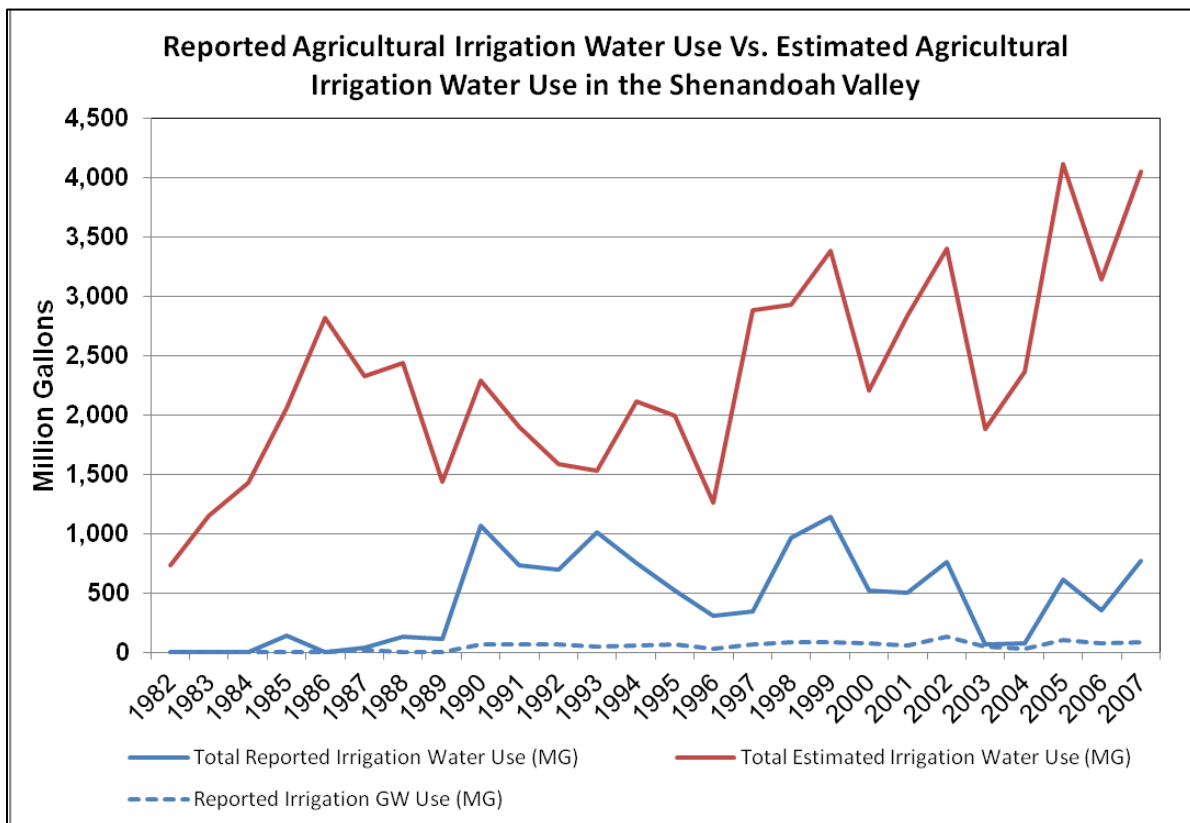


Figure 16: Comparison of reported irrigation water use to estimated irrigation water use in the Shenandoah Valley for the period 1982 – 2007.

Results

From 1982 – 2007, growing season precipitation recorded at the Dale Enterprise NOAA station ranged from 12” to 38” inches and averaged 21”. No overall climatic trend was noted in the amount of precipitation recorded at the Dale Enterprise station for the period of record analyzed (Figure 15). In an average year, 322,083 gallons of artificial irrigation water per

acre was estimated to be necessary to prevent crop stress and damages to yields. In 1986, the driest growing season in the 25 years of record, only 12” of rain fell in the study area, requiring an estimated 421,402 gallons per irrigated acre. The wettest growing season in the dataset was 1996 when over 38” of rain fell in the study area. The irrigation rate is estimated to have been only 180,019 gallons of water per irrigated acre during that relatively wet growing season.

In the past three decades, the number of acres reportedly irrigated for agricultural purposes in the Shenandoah Valley has increased almost four-fold from 2,212 acres in 1982 to 10,544 acres in 2007 (Figure 15). Rockingham and Augusta counties reported the vast majority of irrigated acreage in 2007 (4,808 and 3,813 acres, respectively) (National Agricultural Statistics Service, 2009; 1999; 1990).

Application of the climatically adjusted irrigation rates to the reported and extrapolated acreage of irrigated cropland in the study area yields total yearly estimated agricultural irrigation water use ranging between 735 MG and 4,109 MG (Figure 16, Table 7).

The estimation results appear to indicate a significant degree of under-reporting by agricultural irrigators in the Shenandoah Valley. Total estimated water use by agricultural irrigators was over 5 times higher than reported in 2007. Estimated irrigation water use was an order of magnitude or more higher than what was reported throughout the entire period but interestingly, the pattern of estimated water use follows the deviations found in the reported data. Overall, the estimated water use for this sector followed a first order growth trend from 734 MG in 1982 to 4,042 MG in 2007.

Future estimations could be refined by employing more complicated statistical regression methods and multivariate models (Titus et al., 1990; Smajstrla, A.G. and Zazueta, F.S. 2002) that integrate more variables affecting crop health, but their use would also require the collection of data sources that are not readily available in the study area. The best way to improve our understanding of agricultural-irrigation water use in the study area however, would be the increased measurement and reporting of such activities through increased enforcement of the water withdrawal reporting regulation.

Estimation of Mining Sector Dewatering Water Use

Surface mining is the exclusive type of active mining in the Shenandoah Valley and is used to extract limestone, dolostone and to a lesser extent sand, unconsolidated gravel, shale and clay materials throughout the region. In 2010, thirty-three (33) active quarry and open pit mines excavated and processed a reported 6,617,977 tons of rock material such as crushed stone for roadways, cement and concrete, agricultural lime, and sand for glass from the study area (VDMME, 2012).

Long-term dewatering is necessary at some surface mines to prevent flooding of active quarry pits and to enable access for drilling, blasting and loading of mined rock material. Mine dewatering is a form of groundwater extraction similar to water well pumping, the only difference being the diameter of the hole in the ground. Interestingly, when abandoned quarry pits are used for non-mining purposes as they are in Frederick County, they are reported as surface water withdrawals. Virginia's water use regulation exempts water withdrawals for mine dewatering from reporting requirements therefore only water used to process mined materials populates VWUDS. Estimation of pit dewatering activity in the region was necessary to approximate true water use by this sector.

Methodology

Although withdrawals for quarry pit dewatering are not reported to VWUDS, mine dewatering is known to produce large volumes of water, the vast majority of which must be discharged to nearby surface waters. These point discharges are regulated through the Virginia Pollutant Discharge Elimination System by a general permit (VAC 25-31-170 et seq.). In order to comply with the terms of the general permit, mine operators must self-report the volume and quality of water discharge from their

property quarterly in the form of a Discharge Monitoring Report (DMR).

For this report, all mines in the Shenandoah Valley with active general permits were investigated for discharge information. In total, paper files from nineteen (19) general permits with approximately fifty (50) individual discharge outfalls were evaluated for flow and locational information. Quarterly data from 2007 was compiled for outfalls that listed mine pit dewatering, and groundwater infiltration exclusively as discharge sources but at some outfalls, dewatering discharges were comingled with storm water. Outfalls that conveyed storm water exclusively were not included for the purposes of this report.

All discharge flow rates reported on the DMRs were average daily values and all facilities in the Shenandoah Valley reportedly estimated these values from periodic volumetric tests or from electricity consumption on pumps. In this report, the estimated daily flows listed on each quarterly DMR were multiplied by the number of days in the reporting period to produce estimates of quarterly and yearly water withdrawal for each facility. Unfortunately, mine operators are not required to report how many days pumping actually occurred during a quarter. This reporting limitation means that this estimation method will overestimate groundwater withdrawals at facilities that pump periodically throughout the reporting period. Future studies are necessary to reduce uncertainties associated with this estimation method.

Results

In 2007, fourteen (14) surface mine facilities reported mine dewatering in the Shenandoah Valley.

Estimated groundwater withdrawals for dewatering activities totaled 2,670 MG in 2007. Combining the estimated dewatering withdrawals with reported mining sector process water withdrawals from VWUDS for 2007 (39MG) would bring the total water use by this sector to be approximately 2,709 MG. Groundwater withdrawals estimated from DMRs for each facility ranged between 15 MG and 531 MG. The average daily withdrawal rate for quarry pit dewatering in the valley, assuming that all reported quarterly values reflected continuous dewatering, was 0.5 MGD in 2007 (Tables 8 & 9, Appendix 5b).

Estimation of Total Water Use in the Shenandoah Valley

Reported water use was combined with estimated domestic, irrigation, agricultural and mine-dewatering water use to obtain an approximation of total water use in the Shenandoah Valley. Total reported and estimated water use for the region was 38,637 MG in 2007 (approximately 106 MGD) (Figure 17). Major demand sectors include public water supply systems and manufacturing with 17,079 MG (~47 MGD, 44%) and 6,182 MG (~ 17 MGD, 16%) respectively. Estimated self-supplied domestic water use was projected to have been the third largest demand in the valley at 5,655 MG or 15% of total water use for 2007 (~ 15 MGD). Estimated irrigation and mining withdrawals shared approximately 17% of the total water use in the valley at 4,042 MG (~11 MGD) and 2,709 MG (~7 MGD) respectively. Estimated agricultural livestock and reported commercial water use accounted for 2,640 MG (~7MGD) and 320 MG (~0.8MGD) of water use respectively.

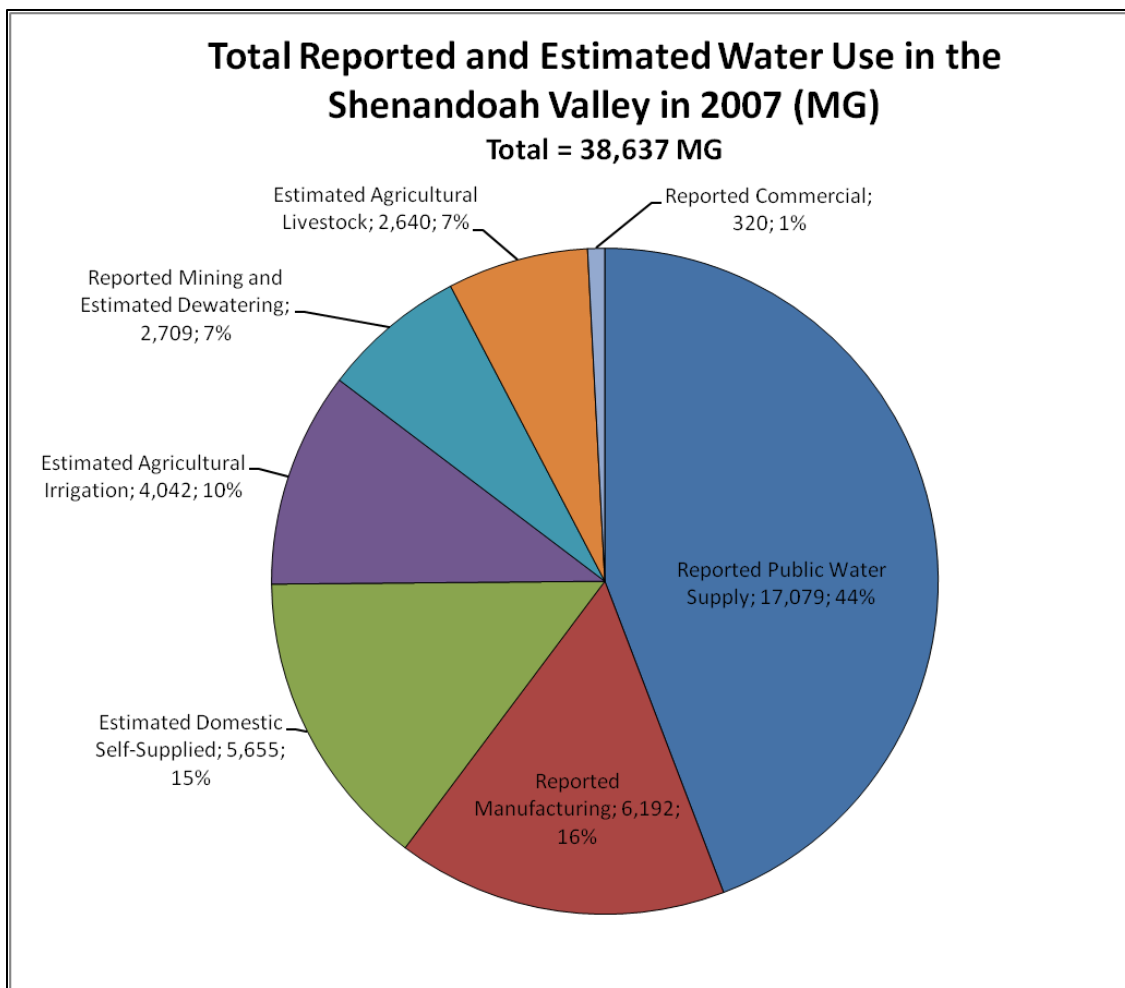


Figure 17: Comparison of reported water use to estimated use in the Shenandoah Valley for 2007.

Spatial Analysis of Reported Water Withdrawals

Surface water and groundwater withdrawal locations were plotted in GIS to analyze the spatial distribution of water use in the region for the year 2007. Groundwater withdrawals were examined to determine which rock types and geologic formation groupings in the region were most heavily utilized and to identify areas that may be stressed due to high groundwater extraction rates. Agricultural livestock, irrigation, and self-supplied domestic water use estimations were not analyzed spatially due to limitations in county-scale datasets used to generate the estimates.

Distribution of Reported Water Withdrawals

In 2007, seventy (70) MPIDs (Measuring Point Identifications) reported a total of 11,079 MG of surface water withdrawals throughout the Shenandoah Valley (Figure 18, Appendix 4). Six (6) of the surface water withdrawals reported in 2007 had missing or obviously incorrect location information. The six MPIDs were all agricultural-irrigators that reported surface water withdrawals totaling 110.8 MG. Evaluation and

field checking of surface water MPID locations was outside the scope of this study but a handful of surface water MPIDs were updated with post-processed GPS when encountered during facility inspections that targeted groundwater withdrawal points.

Approximately 56% of surface water withdrawals in 2007 (6,164 MG) were reportedly obtained from waterways and quarries in the northern part of the valley (~ north of 39° latitude). The majority were withdrawals to supply municipal systems in the area. The largest surface water withdrawal in the northern valley totaled 3,109 MG (~8.5 MGD) from the North Fork of the Shenandoah River to supply the City of Winchester.

In 2007, one hundred and seventy-five (175) MPIDs reported 13,727 MG of groundwater withdrawals in the study area (Figure 19, Appendix 5a). In the same year, fourteen (14) surface mining facilities dewatered an estimated 2,669 MG of groundwater into local streams and rivers. Approximately 54% of the volume of groundwater withdrawals (8,920 MG) was obtained from extreme south-eastern Augusta and Rockingham Counties.

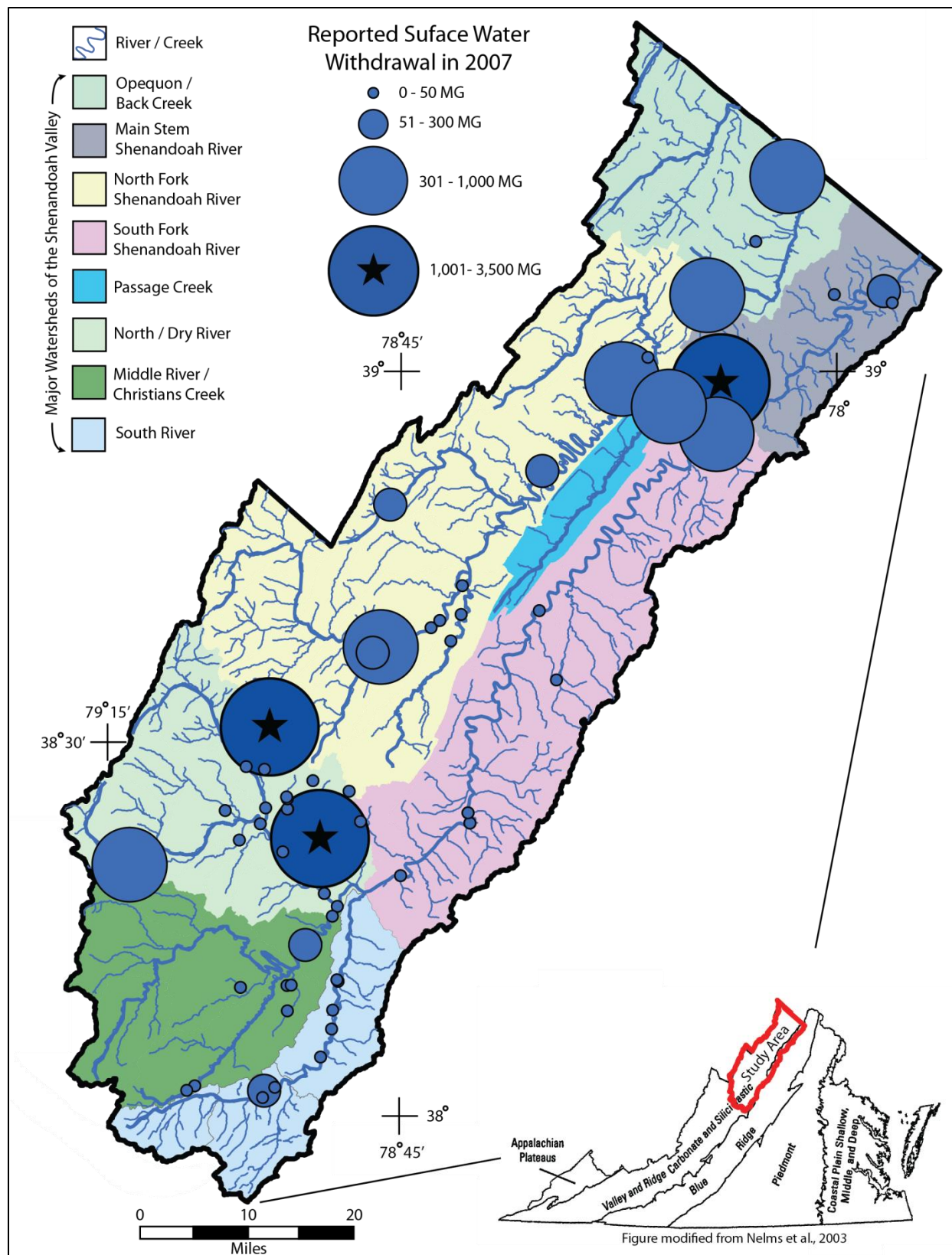


Figure 18: Reported surface water withdrawals in 2007 superimposed on the major surface watersheds contained in the study area. Symbol size proportional to magnitude of withdrawal.

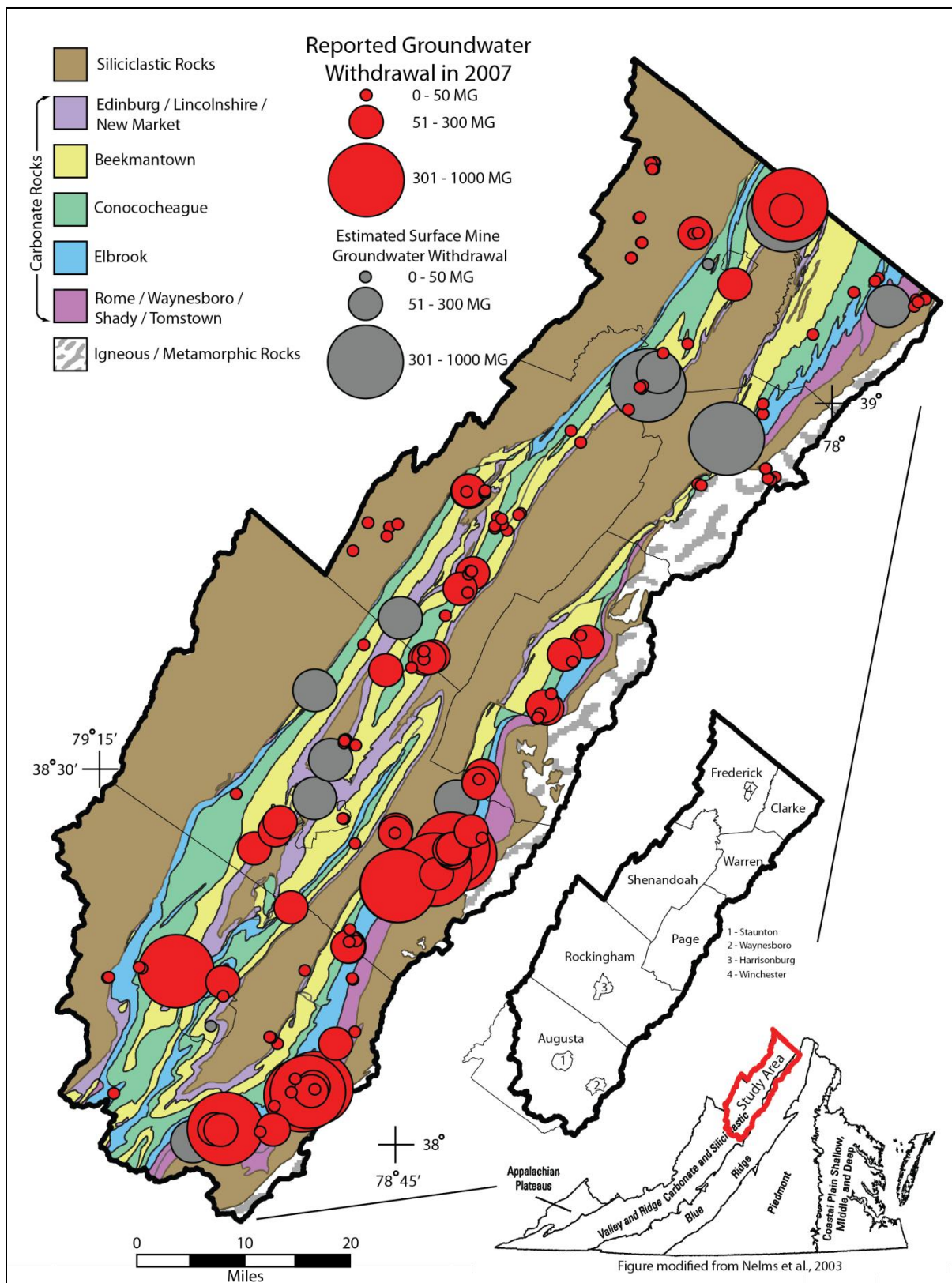


Figure 19: Reported groundwater withdrawals in 2007 superimposed on generalized Geologic Map of the Shenandoah Valley. Symbol size proportional to magnitude of withdrawal. (Geologic layer modified from 1:500K Virginia Geologic Map, VDGMR 2000).

Water Withdrawals by Watershed

Reported surface water and groundwater withdrawal locations (including estimated quarry dewatering withdrawals) were examined with respect to eight major surface watersheds that drain the Shenandoah Valley (Figure 18 & 20, Table 8).

The North Fork of the Shenandoah River watershed is the largest watershed in the study area, (~929 miles²) draining the majority of Shenandoah county and significant portions of Rockingham and Frederick counties. Major waterways in the watershed include the North

Fork of the Shenandoah River, Linville Creek, Smith Creek, Stoney Creek, and Cedar Run Creek. Headwater portions of the North Fork River, Stoney Creek, and Cedar Run Creek flow to the east out of siliciclastic mountains but then generally turn to the north-east upon entering the valley floor.

The North Fork watershed had the highest total reported water use in the Shenandoah Valley in 2007 (7,168 MG, ~26%) with over 60% being from surface water sources. Twenty percent (20%) of water use in the watershed (1,444 MG) was from estimated surface mine dewatering withdrawals.

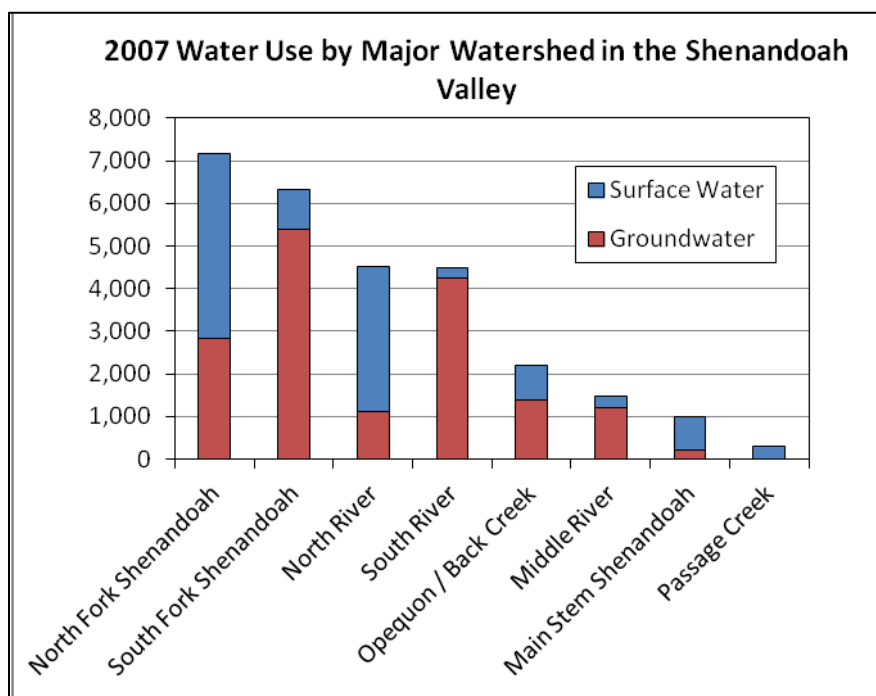


Figure 20: Reported surface water and groundwater withdrawals by major watershed in the Shenandoah Valley. Groundwater totals include estimated surface mine dewatering withdrawals.

The South Fork of the Shenandoah River watershed is the second largest watershed in the study area (~618 miles²), draining large portions of eastern Rockingham county, southern Warren county, and all of Page County. The South Fork of the Shenandoah River is the main waterway in the watershed, flowing in a northeasterly direction at the foot of the Blue Ridge Mountains to the east and the Massanutten Mountain Range to the west. It is formed by the confluence of its

tributaries the North, Middle, and South Rivers near the town of Port Republic. The South Fork watershed had the second highest total water use in 2007 (6,322 MG), with the vast majority (~85%) of withdrawals sourced by groundwater. A minimal amount of surface mine dewatering withdrawals were estimated in the watershed for 2007 (88 MG).

The North River and South River watersheds each had the third highest reported

total water use in the study area (4,504 MG and 4,500 MG, respectively). The North River watershed is the third largest in the study area (~445 miles²) draining the southwestern portion of Rockingham County and northwestern Augusta County. Dry River and North River flow southeastward from the siliciclastic mountain highlands in the western part of the watershed and join at the Town of Bridgewater. Unlike most waterways in the study area, North and Dry Rivers continue a southeastward trend after reaching the carbonate rocks of the valley floor. Approximately 75% (3,386 MG) of reported withdrawals in the watershed in 2007 were from surface water sources.

The South River watershed is the second smallest watershed in the study area (~234 miles²) and drains a significant portion of eastern Augusta County and a small portion of southeastern Rockingham County. The South River runs in an overall northeasterly direction along the foot of the Blue Ridge Mountains. Over 94% (4,242 MG) of reported withdrawals in the watershed originated from groundwater sources in 2007. An estimated 287 MG of surface mine dewatering withdrawals were estimated to have occurred in the watershed that same year.

Approximately 335 miles² of the Opequon and Back Creek watershed is in Virginia. The Opequon, Back, and Sleepy are creeks that drain the northwestern portion of Frederick County directly into the Potomac River. The waterways run northeast through a watershed that is underlain predominantly by siliciclastic rock types. In 2007, 2,201 MG of water use was reported in the watershed, with approximately 62% of that volume (1,371 MG) supplied by groundwater withdrawals. Approximately 36% of total groundwater use in the watershed (500 MG) was from estimated surface mine withdrawals for pit dewatering.

The Middle River watershed is the fourth largest in the study area (~374 miles²) and drains a significant portion of central Augusta County. The watershed is underlain predominantly by

calcium carbonate rocks. Middle River and Christians Creek are the major waterways in the watershed and flow generally to the northeast. In 2007, 1,478 MG of water use was reported in the watershed, with the majority (82%, 1,215 MG) from groundwater sources. An estimated 99 MG was from surface mine withdrawals for pit dewatering.

The Virginia portion of the watershed that feeds the main stem of the Shenandoah River is located in Clarke and Warren Counties and continues into West Virginia where it joins with the Potomac River at Harpers Ferry. The main stem of the Shenandoah River forms in Front Royal where the South and North Forks of the Shenandoah River join. In 2007, 1,002 MG of water use was reported in the watershed, with the majority (77%, 781 MG) from surface water sources. An estimated 94 MG was from surface mine withdrawals for pit dewatering.

Passage Creek watershed is the smallest in the study area (~88 miles²) and drains the interior highlands of the Massanutten Mountain range which are almost entirely composed of siliciclastic rocks. Passage Creek flows to the northeast and drops out of the mountain range west of Strasburg where it joins the North Fork of the Shenandoah River. In 2007, one facility withdrew 301 MG of surface water in the watershed. No groundwater withdrawals of any type were reported in the watershed.

Groundwater Withdrawals by Rock Type and Formation Grouping

Reported groundwater withdrawals and locations of estimated mine dewatering withdrawals were grouped by specific rock types, and groupings of geologic formations. Geologic formations are mappable bodies of rock that have distinctive mineralogical, structural, or textural characteristics that set them apart from the rock bodies with which they are in contact (Dolgoff, 1998). Geologic formation boundaries are based on the 1:500,000 scale Virginia Geologic Map and are recognized as locally imprecise and may be off by tens to hundreds of meters (VDMR, 1993). Formations that were composed of predominantly siliciclastic or metamorphic rock types were grouped together due to the small number of reported groundwater withdrawals found in individual formations of these rock types. The comparison of groundwater use by geologic formation groupings is not meant to imply hydraulic continuity, or to denote aquifer boundaries as groundwater flow paths often cross formational boundaries in the karst terrain of the Valley and Ridge Province due to fracture and solution-enhanced conduit flow.

Surface areas of the various rock types were calculated in GIS using the 1:500,000 scale Virginia Geologic Map. Siliciclastic (predominantly sandstones, siltstones and mudstones) and calcium- and magnesium-carbonate (limestone and dolostone) rock-types underlie the majority (93% or 3,057 square miles, Figure 21) of the Shenandoah Valley. The surface area of siliciclastic rock units slightly exceeds that of carbonate rock types (47%, 1,542 miles², and 46% 1,515 miles², respectively).

Although similar in aerial extent to siliciclastic rock units, withdrawals from carbonate aquifers account for the vast majority (95%, Figure 22) of reported and estimated groundwater withdrawals in the watershed. Igneous and metamorphic rock types account for a small portion of the bedrock exposed in the watershed (~7%, 216 square miles). Similarly, groundwater reportedly withdrawn from igneous and metamorphic rocks in the Valley in 2007 was relatively miniscule (<1%, Figure 22). Approximately 54% of all groundwater reportedly withdrawn in the valley in 2007 originated from forty-three (43) wells and springs, and two (2) surface mines in eastern Rockingham and Augusta counties at the foot of the Blue Ridge Mountains.

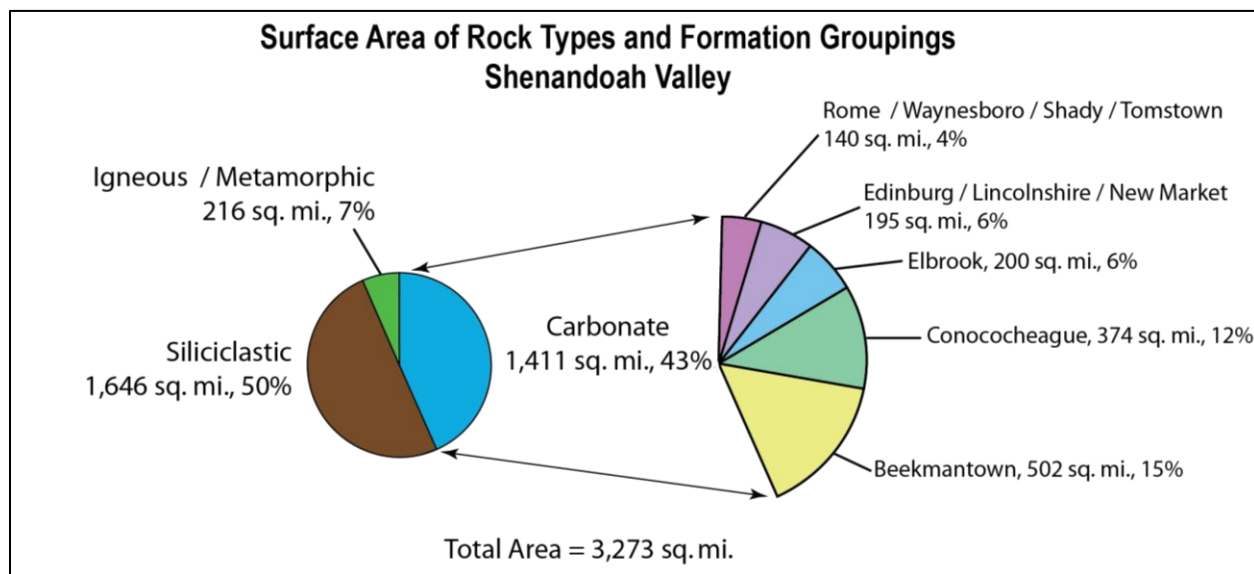


Figure 21: Calculated surface areas of major rock units in the Shenandoah Valley. (Areas calculated from rock type shapefiles obtained from 1:500,000 Virginia Digital Geologic Map, VDMR 2000 and viewed as approximations).

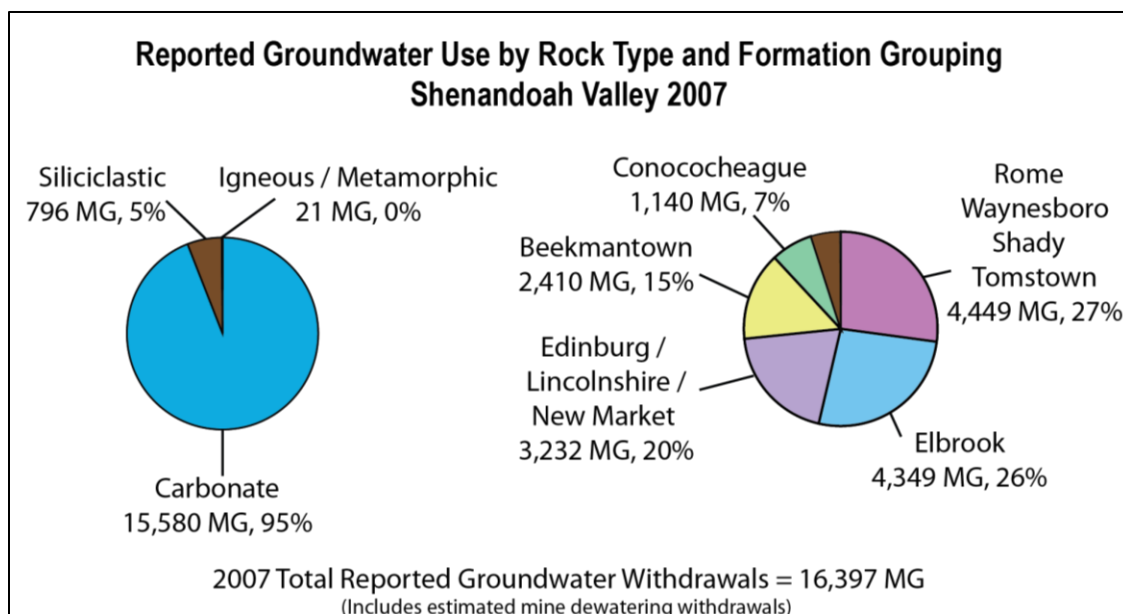


Figure 22: Groundwater withdrawals reported in the Shenandoah Valley by rock type and formation groupings in 2007.

Igneous Metamorphic Rock Units

Igneous and metamorphic rock types of the Blue Ridge Province form the eastern edge of the Shenandoah Valley (Figure 19). Middle Proterozoic Charnockite and Late Proterozoic / Cambrian Catoctin Meta-basalts form the slopes and ridges of the Blue Ridge. The charnockite units are dusky-green, mesocratic, coarse- to very-coarse-grained, equigranular to porphyritic, foliated pyroxene-bearing granite to granodiorites. Catoctin meta-volcanics are commonly grayish-green to dark-yellowish-green, fine-grained, schistose chlorite- and actinolite-bearing metabasalts (Berquist et al, 1993). Triassic age igneous intrusive dikes and volcanic plugs, although present throughout portions of the valley, were not included in this report due to their small scale.

In 2007, a total of 20.90 MG of groundwater was reported to have been withdrawn from seven (7) wells and two (2) springs in Igneous and Metamorphic rock units (Figure 22, Appendix 5a & 5b). Water well withdrawal volumes from this unit ranged between 1.11 to 3.45 MG in 2007. Two springs provided 1.13 and 5.93 MG of groundwater that same year. All groundwater withdrawn from the Igneous and Metamorphic Units was for small

Public Water Supplies in Warren County. No mining dewatering activities are known to have occurred in igneous-metamorphic formations in 2007.

Siliciclastic Rock Units

Geologic formations that are predominantly composed of siltstone, sandstones and/or mudstone rocks have been grouped together due to the relative small utilization of these units as water supplies. This grouping is composed of the following geologic units from the 1:500,000 Geologic Map of Virginia (Virginia Division of Mineral Resources, 1993): **Cch** – Chilhowee Group, **Om**– Martinsburg / Orando, **Oun** – Juniata, Oswego, Eggleston, **Oz** – Landslides of predominantly Ordovician Units, **Skrt** – Keefer, Rose Hill, Tuscarora, **Sm** – Massanutten Sandstone, **SOz** – Landslides of predominantly Ordovician and/or Silurian units, **DSOz** – undivided units of Devonian, Silurian, and Ordovician age, **Dma** – Mahantango, **Dmn** – Millboro / Needmore Shale, **Dmn** – Marcellus Shale, **Db** – Brallier, **Dch** – Chemung, **Dhs** – Hampshire, **Mpo** – Pocono, **DSu** – Ridgeley, Helderberg, and Cayuga Groups.

In general, members of the siliciclastic map unit make up most of the topographically

higher portions of the Shenandoah Valley, but also occupy broad undulating plains where shale or mudstone is the dominant lithology (Figure 19). Siliciclastic rocks account for approximately 47% of the surface area in the Valley, but only accounted for approximately 6%, or 796 MG of groundwater reportedly withdrawn from the study area in 2007 (Figures 25 & 28). Well withdrawals for the 40 individual MPIDs ranged from 0.01 MG to 108.95 MG and averaged 19.73 MG. (Appendix 5a). Only one spring located in silici-clastic rock types reported groundwater withdrawals in 2007 (1.01 MG).

Reporting groundwater users in the siliciclastic formations included public water supply, manufacturing, mining (process-water), and commercial sectors. No mining dewatering activities are known to have occurred in siliciclastic formations in 2007. Most groundwater use in siliciclastic rock types was for small to moderate sized public water supplies that used a network of low yielding wells to supply housing subdivisions. The highest reported withdrawal from a public water supply well in this unit in 2007 was 108.95 MG but most individual public water supply wells reported 1-30 MG. Many public system operators in this unit reported increased expense associated with treatment for iron and manganese and difficulties maintaining adequate sustained well yields.

Carbonate Rock Units

The vast majority (95%, 15,580 MG) of groundwater obtained by reporting users in the Shenandoah Valley in 2007 was supplied by calcium- and magnesium-carbonate rocks of Cambrian and Ordovician age (Figure 22). Folded and faulted carbonate units extend the length (~107 miles) of the study area striking in a general northeast – southwest orientation and can be roughly divided into western and eastern carbonate belts between ¾ to 11 miles wide. (Figure 19).

Since the vast majority of groundwater extracted in the Shenandoah Valley originates from carbonate aquifers, the descriptions of water use characteristics of the carbonate rocks were further subdivided into individual formations or groups of smaller formations.

Cambrian Rome, Waynesboro, Shady, and Tomstown Formations

The Rome Formation was named by Hayes in 1891 in its type locality in Rome, Georgia. The same unit was named the Waynesboro Formation in 1906 by Stose in Waynesboro, Pennsylvania (Butts, 1940). Similar north-south naming confusion exists for the unit underlying the Rome (Waynesboro) formation. The Shady Dolomite conformably underlies the Rome (Waynesboro) formation and was named by Keith in 1903 from Shady Valley, Johnson County, Tennessee. Stose named a corresponding unit from Tomstown, Pennsylvania in 1906 the Tomstown Limestone. It is now known that both units are the same formation (Butts, 1940). In the Shenandoah Valley, the Rome (Waynesboro) consists predominantly of red and green shale and sandstone beds with thick beds of dolomite, and limestone having a strong resemblance to the underlying Shady (Tomstown) Formation (Brent, 1960). In the Shenandoah Valley, the Shady (Tomstown) is predominantly a dolomite but includes significant limestone. The unit is known to be deeply weathered and therefore is rarely exposed at the surface.

Units of the Rome, Waynesboro, Shady and Tomstown formations underlie only 4% of the watershed, or approximately 140 miles² making it one of the least common rock units in the area, but also one of the most heavily utilized (Figures 21 & 22).

In 2007, approximately one-third (27%, 4,449 MG) of the reported and estimated groundwater withdrawals in the Shenandoah Valley originated from the Rome, Waynesboro, Shady, and Tomstown formations. This group of Cambrian age formations is found almost

exclusively in the eastern portions of the Valley abutting siliciclastic, igneous and metamorphic rocks of the Blue Ridge Mountains. These highly productive aquifers are thin and laterally discontinuous, outcropping in a general NE-SW trend. Although the formation group is found along the entire eastern portion of the Shenandoah Valley, large-scale groundwater extraction is almost entirely limited to eastern Augusta and Rockingham counties. This is primarily due to the presence of thick alluvial fans of unconsolidated, coarse, siliciclastic material that overly much of the Rome, Waynesboro, Shady, Tomstown, and Elbrook outcrop belts in the southern portion of the Shenandoah Valley. The amalgamated alluvial fans may exceed 100 feet in thickness (Hinkle & Sterrett, 1976) and enhance solution flow in underlying carbonate units by effectively capturing and forcing acidic surface drainage from the Blue Ridge into underlying carbonate units (Plummer et. al., 2000).

In 2007, nineteen (19) wells reported annual groundwater use from the Rome/Waynesboro, Shady, and Tomstown formations ranging from 0.1 MG to 602.8 MG and averaging 214 MG. Two (2) spring users reported 12.65 MG and 316.35 MG of groundwater withdrawals. Two (2) surface mines reported estimated groundwater withdrawals of 381 MG (Appendix 5a & 5b).

Reporting groundwater users in these formations included public water supply and manufacturing sectors and one irrigation user. Public water supplies accounted for a little over half of the total reported ground water withdrawals from these units in 2007. Sustained groundwater yields in these rock-types are often prolific enough to adequately supply a moderate to large community on a single well. The city of Waynesboro reported 1,133 MG of withdrawals from just two (2) wells in 2007.

Cambrian Elbrook Formation

The Elbrook formation is composed primarily of dolomite with interbeds of impure

clayey blue limestone and some shale in places (Brent, 1960; Edmundson 1945). The Elbrook is in conformable and gradational contact with the underlying Rome (Waynesboro) Formation and overlying Conococheague Formation (Gathright et al, 1993). In the study area, the Elbrook formation forms laterally discontinuous NE-SW trending belts on the eastern and western portions of the Shenandoah Valley and to a lesser extent, central Augusta and Rockingham Counties. The Elbrook Formation is mapped as underlying approximately only 6% of the region, an area of roughly 200 miles² (Figure 21). In the eastern portions of Augusta and Rockingham counties, areas mapped as Elbrook formation approach 3 miles in width and are mantled by coarse siliciclastic alluvial material.

Twenty-six percent (26%, 4,349MG , Figure 22, Table 9) of groundwater reportedly withdrawn in the Shenandoah Valley in 2007 was from the Elbrook formation of Cambrian Age, the vast majority (~81%, 3,541 MG) of groundwater pumped from the Elbrook formation in 2007 was withdrawn from eastern Rockingham County. No mine dewatering withdrawals are known to have occurred in the outcrop belt in 2007.

In 2007, twenty-nine (29) wells reported annual groundwater use from the Elbrook formation ranging from 1.96 MG to 481.1 MG and averaging 149 MG. Two (2) spring users reported a total of 35.92 MG of ground water supplied from the Elbrook formation. Reported groundwater withdrawals from the Elbrook Formation are used for manufacturing, public water supply, irrigation and commercial purposes. Manufacturing sector withdrawals accounted for roughly 89% of reported use, with 15 relatively shallow wells that pumped an average of 229 MG each in 2007 (Appendix 5a).

Cambro-Ordovician Conococheague Formation

The Conococheague Formation is predominantly limestone with significant dolomite and sandstone beds throughout.

Distinguishing features include thin, undulating siliceous partings that weather out in relief giving the rock a “ribbon-rock” appearance and the occasional presence of stromatoporoid mounds. In Frederick, Clarke and Warren counties, the Conococheague Formation is predominantly a bluish-gray limestone containing beds of dolomite of variable thickness. Dolomite becomes more abundant to the southwest, and in Augusta County is reported to account for half of its estimated thickness (Edmundson, 1945). Lenses of sandstone beds are irregularly distributed throughout the formation and range from 1 to 100 feet thick, but are generally less than 20 feet thick. The sandstone beds are composed of relatively large, well-rounded grains of quartz cemented by calcite, weathering to porous, friable sandstone (Butts, 1940).

The Conococheague Formation is an extensive carbonate rock-type in the Shenandoah Valley. Multiple belts of the Conococheague run for tens of miles trending NE-SW (Figure 19). Exposure areas in portions of western Rockingham and Augusta counties are over four miles wide. The Conococheague Formation is the second most common carbonate unit in the valley and is mapped in approximately 11% of the study region, an area of approximately 374 miles² (Figure 21).

In 2007, a total of 1,140 MG (~7%) of reported and estimated groundwater withdrawals were obtained from rocks of the Conococheague Formation (Figure 22, Table 9, Appendix 5a & 5b). Two (2) mining facilities located in the outcrop belt reported an estimated 230 MG of groundwater withdrawals. Almost half of the reported groundwater withdrawals from the Conococheague Formation in 2007 were from spring sources rather than wells. In 2007, five (5) municipal springs supplied almost as much water (428.10 MG) than was pumped by twenty-six (26) production wells (481.27 MG). Spring use ranged from 30.18 MG to 191.23 MG and averaged 85.62 MG. Reported well use in the formation ranged from 0.03 MG to 88.18 MG and averaged 18.51 MG. Estimated mine

dewatering withdrawals from the outcrop belt ranged from 36 MG to 194 MG in 2007.

Reporting groundwater users in the Conococheague Formation included public water supply, manufacturing, irrigation and agricultural sectors in 2007. Public water supply was the primary user of groundwater obtained from Conococheague Formation rocks in 2007, and was the only sector to utilize springs for water sources from this formation (767.42 MG). A majority of reported groundwater use in this formation was in eastern Page and central Shenandoah counties.

Ordovician Beekmantown Formation

The composition of the Beekmantown Formation varies throughout the region. In Augusta and Rockingham counties, it is mainly fine-grained, dark-gray dolomite with minor amounts of bluish-gray limestone. Limestone becomes the dominant lithology further to the northeast and is thought to compose more than half the thickness of the formation in Frederick and Clarke counties. Distinctive chert occurs at several horizons throughout the formation (Edmundson, 1945). Paleozoic erosion of the exposed Beekmantown depositional environment, also known as the Great Knox unconformity, has produced erosional breccias, local topographic relief, and paleokarst topography (Gathright et al., 1993). Limestones of the New Market Formation lie unconformably above the Beekmantown. The Chepultepec Formation, although not mapped in the study area at the 1:500,000 scale, conformably underlies the Beekmantown formation (Edmundson, 1945; Brent, 1960; Gathright et al. 1977).

The Beekmantown Formation is the most common carbonate unit in the study area. Outcrops of the Beekmantown formation are long, nearly continuous curvilinear belts that cover approximately 500 square miles or roughly 15% of the valley floor. Surface exposure belts of the Beekmantown Formation are almost 4

miles wide in parts of western Rockingham and eastern Frederick County (Figures 19 & 21).

In 2007, a total of 2,410 MG (15%) of reported and estimated groundwater withdrawals were obtained from rocks of the Beekmantown Formation (Figure 22, Table 9). Three (3) mining facilities located in the outcrop belt reported an estimated 634 MG of groundwater withdrawals.

The vast majority of groundwater reportedly extracted from the Beekmantown Formation in 2007 was from wells rather than spring sources. In 2007, thirty (30) well sources reportedly extracted a total of 1,595 MG from the Beekmantown Formation. The maximum reported extraction from a single well source was 288 MG in 2007. Four (4) springs supplied approximately 182 MG to reporting users in 2007. The main uses of groundwater from the Beekmantown formation were for public water supplies (1,053 MG) and Manufacturing (671 MG). The largest users of groundwater from the Beekmantown are in south-central Rockingham County (Town of Dayton and Town of Bridgewater) and western Shenandoah County (George's Chicken). Estimated mine dewatering withdrawals ranged from 15 to 531 MG (Appendix 5a & 5b).

Odovician Edinburg, Lincolnshire, and New Market Formations

The Edinburg Formation is characterized by dark-gray to black, aphanitic to coarse-grained, thinly to thickly bedded limestone with thin, black shale partings with a basal black shale unit in the southern part of the study area (Gathright et al., 1993). The New Market limestone is a light gray, massive and micritic high-calcium limestone that weathers a distinct chalky white-gray and is a major quarry rock in parts of the valley (Edmundson, 1945; Gathright et al., 1977). The Lincolnshire is mainly a gray to black medium-grained, thickly-bedded limestone with abundant black chert along or parallel to bedding planes (Brent, 1960; Gathright et al. 1977). The three formations,

relatively thin individually, were combined in order to map at the larger state map scale. Outcrops of these units in the Shenandoah Valley account for 195 square miles or roughly 6% of the valley floor and are thin and laterally discontinuous (Figure 19).

In 2007, a total of 3,232 MG (20%) of reported and estimated groundwater was obtained from the Edinburg, Lincolnshire, and New Market Formations. Seven (7) quarry operations reported an estimated 1,424 MG of groundwater withdrawals for mine dewatering (Table 9). Almost all of the groundwater reportedly extracted from the the Edinburg, Lincolnshire, and New Market Formations in 2007 was for public water supply uses (~99%, 1,792 MG). Nine (9) well sources extracted 817.17 MG in 2007. Withdrawal of spring water from one (1) spring source (990.31 MG) exceeded the combined extraction from reporting all reported well sources in the outcrop belt (Appendix 5a & 5b). Estimated mine dewatering withdrawals ranged from 55 MG to 463 MG.

Summary

Water use by most sectors in the Shenandoah Valley has increased since the 1980's. Groundwater is the dominant source of reported water withdrawals in the region with wells increasingly being relied on as system owners shift away from spring sources. Since 1989, the public water supply sector has been the largest water user in the valley and continues to increase water consumption at an average rate of 4% per year. Manufacturing sector water withdrawals have declined since 1982, a trend made in part by the closure of some facilities but also in improved efficiencies at some of the larger plants. The manufacturing sector is almost entirely dependent on groundwater wells to supply water for their operations in the region. Reported commercial sector withdrawals are relatively small and exhibit no growth trend.

Agricultural sector withdrawals appear to be largely underreported in the Shenandoah Valley. Conservative estimations suggest that

true water use by this sector may be eight (8) times higher than reported. Similarly, precipitation-adjusted estimations of crop irrigation suggest that the majority of water use by this sector remains unreported in the Shenandoah Valley. Total estimated water use by this sector was approximately five (5) times higher than reported.

Estimations were performed on two other potentially significant water use sectors that are excluded from reporting requirements of the Virginia water use reporting regulation. Estimations of self-supplied domestic withdrawals suggest that distributed groundwater demands from households outside of public service areas will soon surpass reported withdrawals by the manufacturing sector to be the second largest use sector in the valley. Estimated self-supplied domestic water use follows a continuous growth trend similar to the public water supply sector with an average growth rate of 2% per year.

Mining operations are required to report water withdrawals only if used for process water (ie. cooling sand towers or cement mixtures), whereas dewatering withdrawals are excluded from reporting requirements. Active mining operations in the Shenandoah Valley are all open pit mines that often need to pump groundwater to prevent flooding of the excavation. Estimations of water withdrawals calculated from general discharge permits for surface mines in the valley indicate that dewatering activities are much more substantial than previously thought.

Reported and estimated water withdrawals for the Shenandoah Valley totaled 38,637 MG in 2007 (~106 MGD). Reported water withdrawals accounted for approximately 61% of that total, suggesting that regulatory exclusions and underreporting have resulted in the tracking of only two-thirds of actual water use in the region.

Locational information for reporting groundwater users in the study area was reviewed and updated by inspections at several

facilities throughout the valley. Fifty-six percent (56%) of wells and springs that had reported withdrawals between 1982 and 2010 were updated with post-processed digital GPS coordinates. Field work, file research at health department field offices, and geophysical logging was used to increase the percent of groundwater withdrawal points with associated construction information (detailing well depth, sustained yields, depth to water, pump tests and other important hydro-geologic information) from approximately 43% to 88%. Comparison of pre- and post-field work groundwater datasets revealed that improved locational accuracy of groundwater withdrawal points resulted in significant differences in projected water use by geologic formation groupings (Table 9).

The spatial distribution of reported withdrawals and estimated mine dewatering activities was analyzed with relation to major river watersheds and generalized geology of the valley. The North Fork of the Shenandoah was identified as the watershed with the highest reported surface water withdrawals in 2007. The South Fork of the Shenandoah had the highest reported groundwater withdrawals that same year. Over 95% of groundwater withdrawals by volume originate from the calcium-carbonate bedrock aquifers of the valley floor, whereas siliciclastic and igneous / metamorphic rocks found mostly in the mountainous portions of the region are minimally utilized despite representing almost two-thirds of the surface area of the Shenandoah Valley. Approximately 54% of all reported groundwater use in the region was withdrawn from two calcium-carbonate rock formation groupings (Rome/Waynesboro, Shady/Tomstown, and Elbrook formations) in eastern Rockingham and Augusta counties at the foot of the Blue Ridge Mountains.

Recommendations for Data Improvements

This study has revealed limitations in the utilization of Virginia's water use database for regional scale analysis. Although work was performed to improve the accuracy of the dataset in the study area, continued work on the following issues would improve future analyses:

- Increased field inspections that include the collection of post-processed digital GPS locations, construction information, and metering methods on every reporting groundwater and surface water withdrawal point in the region.
- Increased education and enforcement of reporting requirements among agricultural and irrigation system owners.
- Consistent use of totalizers or other method of measuring cumulative withdrawal volumes at each individual well, spring, quarry pit, or surface water intake.
- Increased oversight of new online self-submittal process. Instances were found where reported water use abruptly ceased

once online self-submittal procedures were instituted.

- Increased oversight and consistent reporting of transferred water would improve the accuracy of total water consumption by individual system owners.
- Implementation of pilot studies at farms and irrigated fields in the study area to refine the water use coefficients used in estimations with real-world localized data.
- Reporting of total quarterly discharge volume or number of days discharge occurred during the period on mine discharge monitoring reports would decrease unknowns in water use estimation methods for this sector.

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TABLES

REPORTED WITHDRAWALS							
YEAR	Well Use (MG)	Spring Use (MG)	Groundwater Use (MG)	Surface Water Use (MG)	Total Reported Water Use (MG)	USGS Groundwater Use (MG)	USGS Surface Water Use (MG)
1982	7,813.67	3,668.79	11,482.46	16,356.87	27,839.33		
1983	7,185.69	3,008.81	10,194.50	15,251.58	25,446.08		
1984	7,168.86	3,692.28	10,861.14	15,565.35	26,426.49		
1985	7,006.14	3,644.33	10,650.47	16,178.84	26,829.32	10,705.45	16,275.35
1986	7,192.49	3,756.08	10,948.57	13,992.19	24,940.75		
1987	7,298.43	3,703.70	11,002.13	14,543.53	25,545.66		
1988	7,322.42	4,297.15	11,619.57	15,629.45	27,249.02		
1989	7,411.75	4,361.26	11,773.01	9,121.51	20,894.52		
1990	7,896.13	3,719.68	11,615.80	9,854.98	21,470.79	11,727.45	11,234.70
1991	8,206.86	2,722.27	10,929.13	8,546.59	19,475.72		
1992	8,169.92	3,422.64	11,592.56	8,456.83	20,049.39		
1993	8,516.18	3,726.98	12,243.16	8,766.29	21,009.45		
1994	9,159.19	3,885.17	13,044.36	8,493.95	21,538.31		
1995	8,662.79	3,493.40	12,156.19	8,556.64	20,712.83	12,410.00	9,964.50
1996	10,335.97	3,468.10	13,804.07	8,653.85	22,457.92		
1997	10,655.97	3,220.16	13,876.13	9,226.28	23,102.41		
1998	10,637.88	3,283.50	13,921.39	9,899.37	23,820.75		
1999	10,464.75	3,337.56	13,802.32	10,646.07	24,448.39		
2000	10,899.60	2,864.10	13,763.69	9,570.21	23,333.90	14,457.65	9,256.40
2001	10,697.74	2,894.99	13,592.73	9,869.18	23,461.91		
2002	10,798.62	2,681.16	13,479.78	9,709.68	23,189.46		
2003	9,436.53	2,855.29	12,291.82	9,505.56	21,797.38		
2004	10,330.69	2,772.77	13,103.45	9,558.80	22,662.25		
2005	10,302.66	2,518.70	12,821.35	10,394.61	23,215.97	12,939.25	10,468.20
2006	11,348.37	2,028.05	13,376.42	10,626.52	24,002.94		
2007	11,747.54	1,979.49	13,727.02	11,078.72	24,805.74		
2008	11,846.32	1,694.94	13,541.25	10,489.34	24,030.59		
2009	10,960.06	1,478.68	12,438.83	10,241.52	22,680.35		
2010	11,001.22	1,800.07	12,801.30	11,585.31	24,386.61	N/A	N/A
AVE	9,326.70	3,102.76	12,429.47	11,047.23	23,476.70	12,447.96	11,439.83
MIN	7,006.14	1,478.68	10,194.50	8,456.83	19,475.72	10,705.45	9,256.40
MAX	11,846.32	4,361.26	13,921.39	16,356.87	27,839.33	14,457.65	16,275.35

Table 1: Reported withdrawals in the Shenandoah Valley by source type. MG = Million Gallons.

USGS data compiled from quinquennial water use publications.

N/A = 2010 USGS data not available at time of publication.

PUBLIC WATER SUPPLY SECTOR REPORTED WATER WITHDRAWALS							
YEAR	Well Use (MG)	Spring Use (MG)	Groundwater Use (MG)	Surface Water Use (MG)	Total Water Use (MG)	USGS PWS Groundwater Use (MG)	USGS PWS Surface Water Use (MG)
1982	1,303.30	2,545.32	3,848.62	6,420.81	10,269.43		
1983	1,074.38	2,232.22	3,306.59	6,439.34	9,745.93		
1984	1,121.34	2,701.68	3,823.02	6,610.69	10,433.70		
1985	1,070.44	2,753.63	3,824.07	6,665.76	10,489.83	3,887.25	6,529.85
1986	1,363.01	2,724.93	4,087.94	6,416.05	10,503.99		
1987	1,259.99	2,603.54	3,863.52	6,867.57	10,731.09		
1988	1,111.35	2,923.52	4,034.87	7,045.34	11,080.21		
1989	1,163.41	3,175.01	4,338.43	6,885.97	11,224.40		
1990	1,517.52	3,059.11	4,576.63	6,999.28	11,575.90	3,646.35	7,997.15
1991	1,563.38	2,659.15	4,222.53	7,355.57	11,578.10		
1992	1,668.07	3,101.80	4,769.86	7,201.12	11,970.98		
1993	1,776.71	3,455.07	5,231.78	7,271.68	12,503.46		
1994	2,370.98	3,680.80	6,051.78	7,078.37	13,130.16		
1995	2,611.03	3,262.71	5,873.74	7,659.52	13,533.26	6,361.95	7,628.50
1996	2,720.53	3,054.50	5,775.02	7,933.05	13,708.08		
1997	2,796.83	3,047.40	5,844.23	8,537.59	14,381.82		
1998	3,019.75	3,007.65	6,027.40	8,812.63	14,840.03		
1999	3,320.35	2,831.25	6,151.60	8,824.45	14,976.05		
2000	3,498.04	2,501.81	5,999.85	8,730.67	14,730.51	5,989.65	8,705.25
2001	3,315.14	2,727.48	6,042.62	9,031.54	15,074.15		
2002	3,707.79	2,449.64	6,157.44	8,696.10	14,853.53		
2003	3,004.82	2,739.43	5,744.25	8,978.81	14,723.06		
2004	3,863.48	2,696.36	6,559.84	8,969.96	15,529.81		
2005	3,910.42	2,333.94	6,244.36	9,339.64	15,584.00	6,062.65	9,311.15
2006	4,983.58	1,896.36	6,879.94	9,827.83	16,707.77		
2007	5,666.60	1,600.68	7,267.28	9,811.51	17,078.79		
2008	5,708.28	1,568.25	7,276.53	9,069.31	16,345.84		
2009	4,960.91	1,449.57	6,410.48	8,838.75	15,249.23		
2010	5,033.23	1,709.23	6,742.46	9,236.21	15,978.67	N/A	N/A
AVE	2,775.33	2,637.66	5,412.99	7,984.66	13,397.65	5,189.57	8,034.38
MIN	1,070.44	1,449.57	3,306.59	6,416.05	9,745.93	3,646.35	6,529.85
MAX	5,708.28	3,680.80	7,276.53	9,827.83	17,078.79	6,361.95	9,311.15

Table 2: Public Water Supply reported withdrawals in the Shenandoah Valley. MG = Million Gallons. USGS data compiled from quinquennial water use publications. N/A = 2010 USGS data not available at time of publication.

MANUFACTURING SECTOR REPORTED WATER WITHDRAWALS							
YEAR	Well Use (MG)	Spring Use (MG)	Groundwater Use (MG)	Surface Water Use (MG)	Total Water Use (MG)	USGS Industrial Groundwater Use (MG)	USGS Industrial Surface Water Use (MG)
1982	6,408.82	1,076.88	7,485.69	9,764.72	17,250.42		
1983	6,049.79	739.67	6,789.46	8,769.14	15,558.60		
1984	6,012.11	958.73	6,970.84	8,921.94	15,892.78		
1985	5,890.26	857.60	6,747.86	9,231.23	15,979.08	6,701.40	9,249.10
1986	5,747.85	931.51	6,679.35	7,304.15	13,983.50		
1987	5,936.55	1,039.30	6,975.85	7,506.29	14,482.14		
1988	6,137.28	1,304.80	7,442.08	8,233.59	15,675.67		
1989	6,178.66	1,135.25	7,313.91	2,014.20	9,328.11		
1990	6,239.74	588.11	6,827.86	1,655.34	8,483.20	7,931.45	2,014.80
1991	6,438.26	20.37	6,458.63	241.36	6,699.99		
1992	6,253.43	294.61	6,548.04	231.43	6,779.47		
1993	6,515.70	153.11	6,668.81	222.93	6,891.74		
1994	6,544.04	104.32	6,648.36	382.62	7,030.98		
1995	5,818.32	137.68	5,956.00	162.58	6,118.58	5,960.45	1,784.85
1996	7,478.48	353.61	7,832.09	314.29	8,146.38		
1997	7,616.11	51.62	7,667.73	119.99	7,787.72		
1998	7,395.78	164.80	7,560.58	74.20	7,634.79		
1999	6,903.29	391.32	7,294.61	15.43	7,310.03		
2000	7,168.03	302.83	7,470.86	25.15	7,496.01	8,402.30	25.55
2001	7,096.24	126.85	7,223.09	38.73	7,261.82		
2002	6,755.04	172.04	6,927.07	24.70	6,951.78		
2003	6,337.46	108.87	6,446.33	0.00	6,446.33		
2004	6,354.62	67.63	6,422.25	18.29	6,440.54		
2005	6,203.65	144.19	6,347.84	19.55	6,367.39	6,482.40	109.50
2006	6,194.56	107.16	6,301.72	17.41	6,319.12		
2007	5,840.45	334.36	6,174.80	17.35	6,192.15		
2008	5,892.92	93.31	5,986.22	6.52	5,992.74		
2009	5,783.26	0.19	5,783.45	15.18	5,798.63		
2010	5,740.41	47.62	5,788.04	9.38	5,797.41	N/A	N/A
AVE	6,376.93	407.18	6,784.12	2,253.71	9,037.83	7,095.60	2,636.76
MIN	5,740.41	0.19	5,783.45	0.00	5,797.41	5,960.45	25.55
MAX	7,616.11	1,304.80	7,832.09	9,764.72	17,250.42	8,402.30	9,249.10

Table 3: Manufacturing sector reported water withdrawals in the Shenandoah Valley. MG = Million Gallons. USGS data compiled from quinquennial water use publications. N/A = 2010 USGS data not available at time of publication.

YEAR	OTHER SECTORS - REPORTED WATER WITHDRAWALS																			
	COMMERCIAL					IRRIGATION					MINING					AGRICULTURAL				
	Well Use (MG)	Spring Use (MG)	Ground water Use (MG)	Surface Water Use (MG)	Total Water Use (MG)	Well Use (MG)	Spring Use (MG)	Ground water Use (MG)	Surface Water Use (MG)	Total Water Use (MG)	Well Use (MG)	Spring Use (MG)	Ground water Use (MG)	Surface Water Use (MG)	Total Water Use (MG)	Well Use (MG)	Spring Use (MG)	Ground water Use (MG)	Surface Water Use (MG)	Total Water Use (MG)
1982	77.25	46.59	123.85	44.83	168.67	23.10		23.10		23.10	1.21		1.21	126.51	127.72					
1983	52.03	36.93	88.96	40.14	129.10	9.13		9.13		9.13	0.37		0.37	2.97	3.34					
1984	34.28	31.87	66.15	31.96	98.11	0.76		0.76		0.76	0.37		0.37	0.77	1.13					
1985	43.32	33.10	76.42	45.22	121.63	1.77		1.77	235.19	236.96	0.37		0.37	1.45	1.81					
1986	72.11	99.64	171.75	247.67	419.42	1.22		1.22	22.49	23.71	0.37		0.37	1.83	2.19	7.94		7.94		7.94
1987	70.68	60.86	131.54	135.44	266.98	22.06		22.06	32.43	54.49	0.48		0.48	1.80	2.28	8.68		8.68		8.68
1988	67.46	68.84	136.30	201.20	337.50			0.00	147.53	147.53	0.48		0.48	1.80	2.28	5.84		5.84		5.84
1989	62.36	51.00	113.36	99.26	212.62	1.11		1.11	120.23	121.34	0.48		0.48	1.84	2.32	5.73		5.73		5.73
1990	56.11	56.61	112.72	95.04	207.76	76.90	15.85	92.74	996.13	1088.87	0.00		0.00	72.20	72.20	5.86		5.86	37.00	42.86
1991	70.34	27.68	98.02	175.43	273.45	114.57	15.07	129.64	667.72	797.36	0.00		0.00	82.50	82.50	20.31		20.31	24.00	44.31
1992	62.93	12.58	75.51	235.82	311.33	110.86	13.65	124.51	629.77	754.28	62.30		62.30	155.70	218.00	12.34		12.34	3.00	15.34
1993	69.07	76.28	145.36	296.70	442.06	77.70	42.52	120.22	929.29	1049.51	60.70		60.70	21.80	82.50	16.30		16.30	23.90	40.20
1994	81.16	73.06	154.22	330.10	484.32	79.10	27.00	106.10	692.11	798.21	62.40		62.40	0.00	62.40	21.50		21.50	10.75	32.25
1995	50.66	73.81	124.47	193.21	317.68	89.08	19.20	108.28	460.82	569.10	72.60		72.60	61.10	133.70	21.10		21.10	19.41	40.51
1996	20.28	60.00	80.28	106.47	186.75	30.08	0.00	30.08	293.33	323.41	74.30		74.30	0.00	74.30	12.30		12.30	6.71	19.01
1997	35.74	71.09	106.83	153.13	259.96	103.69	50.06	153.75	358.19	511.94	80.30		80.30		80.30	23.30		23.30	57.38	80.68
1998	39.96	77.00	116.97	186.20	303.16	107.29	34.05	141.34	824.24	965.57	46.10		46.10	0.00	46.10	29.00		29.00	2.10	31.10
1999	42.34	68.83	111.17	342.08	453.25	115.08	46.16	161.24	959.34	1120.58	62.70		62.70	184.16	246.86	21.00		21.00	320.62	341.62
2000	42.41	59.45	101.87	227.84	329.70	95.02	0.00	95.02	319.82	414.84	78.10		78.10	263.74	341.84	18.00		18.00	3.00	21.00
2001	49.72	23.06	72.78	209.71	282.49	125.73	17.60	143.33	454.22	597.55	88.60		88.60	124.45	213.05	22.31		22.31	10.55	32.86
2002	54.68	37.75	92.44	300.90	393.33	127.30	21.73	149.03	632.18	781.20	131.60		131.60	43.80	175.40	22.21		22.21	12.00	34.21
2003	13.18	6.99	20.17	186.98	207.15	72.07	0.00	72.07	47.97	120.04	0.00		0.00	0.00	0.00	9.00		9.00	291.80	300.80
2004	57.64	8.78	66.42	197.91	264.33	36.49	0.00	36.49	71.50	107.98	2.65		2.65	0.84	3.49	15.80		15.80	300.30	316.10
2005	61.53	20.16	81.69	184.66	266.35	97.89	20.40	118.29	450.57	568.85	7.17		7.17	87.60	94.77	22.00		22.00	312.61	334.61
2006	52.67	24.52	77.19	177.75	254.93	93.15	0.00	93.15	263.08	356.23	6.13		6.13	16.56	22.69	18.30		18.30	323.90	342.20
2007	64.87	28.85	93.71	226.69	320.40	141.69	15.62	157.31	671.56	828.88	17.33		17.33	21.60	38.93	16.60		16.60	330.00	346.60
2008	49.44	19.29	68.73	173.68	242.41	149.95	14.10	164.05	925.03	1089.08	13.77		13.77	13.30	27.07	31.97		31.97	301.50	333.47
2009	47.37	21.57	68.94	100.57	169.51	120.47	7.35	127.82	1014.35	1142.16	11.10		11.10	7.16	18.27	36.95		36.95	265.50	302.45
2010	43.42	26.03	69.45	161.81	231.26	112.01	17.19	129.20	1084.41	1213.61	11.06		11.06	999.00	1010.06	61.10		61.10	94.50	155.60
AVE	53.28	44.90	98.18	176.15	274.33	76.26	17.98	86.65	511.67	545.39	30.79	N/A	30.79	81.95	109.91	19.42	N/A	19.42	130.98	129.44
MIN	13.18	6.99	20.17	31.96	98.11	0.76	0.00	0.00	22.49	0.76	0.00	N/A	0.00	0.00	0.00	5.73	N/A	5.73	2.10	5.73
MAX	81.16	99.64	171.75	342.08	484.32	149.95	50.06	164.05	1084.41	1213.61	131.60	N/A	131.60	999.00	1010.06	61.10	N/A	61.10	330.00	346.60

Table 4: Reported water withdrawals from other sectors in the Shenandoah Valley. Blank cells indicate withdrawal not reported. MG = Million Gallons

ESTIMATED SELF-SUPPLIED DOMESTIC WATER WITHDRAWALS (MG)														
Year	Augusta County	Clarke County	Frederick County	Page County	Rockingham County	Shenandoah County	Warren County	City of Harrisonburg	City of Staunton	City of Waynesboro	City of Winchester	Total Shenandoah Valley @ 60 GPD per person	Total Shenandoah Valley @ 80 GPD per person	Total Shenandoah Valley @ 120 GPD per person
1990	868.22	220.49	738.32	326.17	1,102.76	485.90	391.60	24.21	5.74	5.96	8.33	3,133.27	4,177.70	6,266.55
1991	887.73	217.43	768.67	330.67	1,131.44	493.26	405.32	25.18	5.75	6.01	8.44	3,209.93	4,279.90	6,419.85
1992	902.88	217.14	785.74	334.55	1,154.46	494.74	416.52	25.95	5.76	6.00	8.53	3,264.20	4,352.26	6,528.39
1993	920.99	217.96	804.57	336.11	1,180.91	499.91	424.16	26.63	5.76	5.98	8.67	3,323.75	4,431.66	6,647.49
1994	939.61	218.14	827.14	337.36	1,206.03	501.39	432.22	27.41	5.75	5.98	8.85	3,382.41	4,509.88	6,764.82
1995	960.54	223.08	861.67	340.40	1,242.11	508.08	440.82	27.80	5.72	6.05	8.63	3,468.68	4,624.90	6,937.36
1996	980.51	224.15	883.71	343.57	1,270.43	508.76	451.60	28.72	5.66	6.15	8.64	3,533.93	4,711.91	7,067.87
1997	995.98	227.40	899.00	344.05	1,283.90	518.22	453.94	29.40	5.63	6.19	8.81	3,579.40	4,772.53	7,158.80
1998	1,011.99	226.59	920.57	347.45	1,291.24	526.02	456.44	30.12	5.65	6.14	8.86	3,623.32	4,831.09	7,246.63
1999	1,031.98	228.40	936.74	348.19	1,306.34	532.03	465.73	30.92	5.60	6.21	8.93	3,675.79	4,901.06	7,351.59
2000	1,040.54	230.27	956.36	348.14	1,301.18	538.62	472.65	31.84	5.59	6.30	8.96	3,705.35	4,940.46	7,410.69
2001	1,052.30	234.36	990.82	348.45	1,317.41	550.40	482.67	32.83	5.54	6.34	9.20	3,772.73	5,030.31	7,545.47
2002	1,062.02	235.96	1,022.35	349.86	1,329.77	560.99	494.79	33.77	5.53	6.43	9.34	3,833.11	5,110.82	7,666.23
2003	1,076.74	238.87	1,055.71	353.86	1,342.43	573.04	506.27	34.04	5.54	6.48	9.36	3,901.75	5,202.33	7,803.50
2004	1,096.46	244.40	1,089.03	353.80	1,358.04	587.83	515.81	34.49	5.49	6.54	9.56	3,976.08	5,301.44	7,952.16
2005	1,113.17	249.81	1,129.06	356.52	1,381.85	605.24	530.35	35.14	5.51	6.60	9.70	4,067.22	5,422.96	8,134.43
2006	1,144.15	253.98	1,169.99	361.59	1,400.46	623.74	542.73	36.15	5.52	6.66	9.78	4,166.06	5,554.75	8,332.12
2007	1,162.37	254.53	1,205.74	364.25	1,424.90	633.01	551.46	36.70	5.59	6.66	9.76	4,241.23	5,654.98	8,482.46
2008	1,170.55	256.77	1,228.19	364.04	1,440.27	640.79	558.12	37.28	5.59	6.72	9.87	4,288.64	5,718.19	8,577.29
2009	1,175.15	255.36	1,251.07	362.05	1,455.14	641.14	557.84	38.07	5.55	6.74	9.88	4,318.50	5,758.01	8,637.01
2010	1,173.66	255.71	1,264.44	361.54	1,464.04	644.98	562.86	38.56	5.55	6.75	9.95	4,341.02	5,788.03	8,682.04
AVE	1,036.55	234.80	989.95	348.22	1,304.05	555.62	481.61	31.68	5.62	6.33	9.14	3,752.68	5,003.58	7,505.37
MIN	868.22	217.14	738.32	326.17	1,102.76	485.90	391.60	24.21	5.49	5.96	8.33	3,133.27	4,177.70	6,266.55
MAX	1,175.15	256.77	1,264.44	364.25	1,464.04	644.98	562.86	38.56	5.76	6.75	9.95	4,341.02	5,788.03	8,682.04

Table 5: Estimated yearly self-supplied domestic withdrawals for various regions in the Shenandoah Valley. MG = Million Gallons

YEAR	TYPE	ESTIMATED LIVESTOCK WATER WITHDRAWALS (MG)							
		Augusta County	Clarke County	Frederick County	Page County	Rockingham County	Shenandoah County	Warren County	Shenandoah Valley Total
1982	Cattle (Dairy and Meat)	556.36	111.16	113.45	108.89	763.75	208.10	45.95	1,907.66
	Hogs and Pigs	48.11	4.33	6.80	12.28	45.89	19.41	0.88	137.71
	All Poultry	30.48	0.00	2.33	61.26	293.30	54.88	0.00	442.26
	Total Livestock	634.95	115.49	122.58	182.44	1,102.94	282.39	46.83	2,487.63
1987	Cattle (Dairy and Meat)	541.77	102.84	85.99	105.81	697.49	175.11	33.80	1,742.81
	Hogs and Pigs	21.23	3.53	4.35	8.01	53.81	13.66	1.83	106.42
	All Poultry	45.72	0.00	0.00	88.81	366.81	48.24	0.00	549.58
	Total Livestock	608.71	106.37	90.34	202.63	1,118.11	237.01	35.62	2,398.81
1992	Cattle (Dairy and Meat)	584.26	103.28	91.31	115.00	751.37	178.87	38.00	1,862.08
	Hogs and Pigs	10.89	3.39	4.18	6.98	32.92	6.78	0.35	65.50
	All Poultry	85.91	0.01	0.00	156.92	467.09	67.73	0.00	777.65
	Total Livestock	681.06	106.67	95.49	278.90	1,251.38	253.39	38.35	2,705.23
1997	Cattle (Dairy and Meat)	554.16	86.97	87.18	121.37	750.86	183.75	41.62	1,825.90
	Hogs and Pigs	10.89	3.39	4.18	6.98	32.92	6.78	0.35	65.50
	All Poultry	105.22	0.00	0.02	192.67	573.47	96.27	0.00	967.65
	Total Livestock	670.27	90.36	91.38	321.01	1,357.26	286.80	41.97	2,859.05
2002	Cattle (Dairy and Meat)	556.62	88.47	95.18	105.15	832.79	190.88	38.52	1,907.61
	Hogs and Pigs	0.38	0.19	0.00	5.16	5.55	3.85	0.05	15.19
	All Poultry	118.19	0.02	0.03	197.16	515.99	93.47	0.00	924.86
	Total Livestock	675.19	88.68	95.21	307.47	1,354.34	288.20	38.58	2,847.66
2007	Cattle (Dairy and Meat)	522.58	84.29	70.83	103.47	754.34	204.06	38.09	1,777.66
	Hogs and Pigs	1.17	1.03	0.00	3.72	3.08	9.22	0.16	18.37
	All Poultry	116.70	0.02	0.04	195.06	438.71	93.13	0.02	843.67
	Total Livestock	640.46	85.34	70.87	302.24	1,196.12	306.41	38.27	2,639.71

Table 6: Estimated water withdrawals by Livestock in the Shenandoah Valley. MG = Million Gallons

ESTIMATED AGRICULTURAL-IRRIGATION WATER WITHDRAWALS (MG)						
Year	Irrigated Acres from Census	Irrigated Acres Extrapolated	Irrigated Acres	Precip 4/1-9/30 (inches)	Gallons Per Acre to Maintain 1" per week	Total Estimated Irrigation Water Use (MG)
1982	2213		2,213	21.09	332,071	735
1983		3,330	3,330	17.19	344,561	1,147
1984		4,447	4,447	21.40	321,482	1,430
1985		5,565	5,565	17.18	370,084	2,060
1986		6,682	6,682	12.00	421,402	2,816
1987	7799		7,799	24.61	298,131	2,325
1988		7,171	7,171	17.16	339,674	2,436
1989		6,543	6,543	28.15	219,118	1,434
1990		5,916	5,916	18.58	386,376	2,286
1991		5,288	5,288	17.76	358,680	1,897
1992	4660		4,660	20.24	338,859	1,579
1993		5,239	5,239	18.30	285,913	1,524
1994		5,819	5,819	18.23	363,025	2,112
1995		6,398	6,398	25.94	311,059	1,987
1996		6,978	6,978	38.32	180,019	1,256
1997	7557		7,557	17.92	380,674	2,877
1998		8,069	8,069	17.71	362,753	2,927
1999		8,581	8,581	16.58	394,250	3,383
2000		9,092	9,092	27.52	242,741	2,207
2001		9,604	9,604	17.79	294,873	2,832
2002	10116		10,116	20.72	335,601	3,395
2003		10,202	10,202	35.21	183,820	1,875
2004		10,287	10,287	26.90	229,708	2,363
2005		10,373	10,373	14.32	396,150	4,109
2006		10,458	10,458	26.45	299,760	3,135
2007	10544		10,544	17.41	383,389	4,042
AVE			7,267	21.33	322,084	2,314
MIN			2,213	12.00	180,019	735
MAX			10,544	38.32	421,402	4,109

Table 7: Estimated water withdrawals for irrigation in the Shenandoah Valley adjusted for weekly precipitation as recorded at Dale Enterprise NOAA station. MG = Million Gallons

WATER WITHDRAWALS BY WATERSHED						
Watershed	Area (miles ²)	Reported Surface Water Withdrawals (MG)	Reported Groundwater Withdrawals (MG)	Estimated Mine Groundwater Withdrawals (MG)	Total Groundwater Withdrawals (MG)	2007 Total Water Withdrawals (MG)
North Fork Shenandoah	929.01	4,326.20	1,398.22	1,443.86	2,842.08	7,168.28
South Fork Shenandoah	617.94	933.94	5,301.33	87.60	5,388.93	6,322.87
North River	445.13	3,386.22	959.60	157.68	1,117.28	4,503.50
South River	234.51	257.20	3,955.29	287.10	4,242.39	4,499.59
Opequon / Back Creek	339.35	830.37	870.38	500.09	1,370.47	2,200.84
Middle River	373.68	262.74	1,115.65	99.47	1,215.12	1,477.86
Main Stem Shenandoah	248.59	781.07	126.57	94.04	220.61	1,001.68
Passage Creek	87.76	301.00	0.00	0.00	0.00	301.00

Table 8: Reported water withdrawals and estimated surface mine dewatering withdrawals by major watershed in the Shenandoah Valley for the year 2007. MG = Million Gallons

2007 GROUNDWATER WITHDRAWALS BY FORMATION GROUPING (MG)			
Geologic Units	Reported Withdrawals Before Field Work	Reported Withdrawals After Field Work	Estimated Mine Dewatering Withdrawals
Elbrook	3,596	4,349	0
Rome / Waynesboro / Shady / Tomstown	4,057	4,067	381
Edinburg / Lincolnshire / New Market	1,856	1,807	1,424
Beekmantown	1,712	1,776	634
Conococheague	812	909	230
Silici-Clastic	786	796	0
Igneous Metamorphic	20	21	0

Table 9: Reported groundwater withdrawals by rock-type and formation grouping.
Change in reported groundwater withdrawal due to improved location and reporting accuracy. MG = Million Gallons

APPENDIXES

APPENDIX 1

2010 WATER USE BY OWNER DATA

RANK	OWNER	REPORTED GROUND WATER USE (MG)	REPORTED SURFACE WATER USE (MG)	TOTAL 2010 REPORTED WATER USE (MG)	CATEGORY
1	MERCK & CO	3,107.60	--	3,107.60	MAN
2	WINCHESTER, CITY OF	--	2,459.64	2,459.64	PWS
3	HARRISONBURG, CITY OF	--	2,345.28	2,345.28	PWS
4	FREDERICK COUNTY SANITATION AUTHORITY	400.50	1,456.14	1,856.64	PWS
5	STAUNTON, CITY OF	698.00	684.01	1,382.01	PWS
6	AUGUSTA COUNTY SERVICE AUTH	1,289.48	57.16	1,346.65	PWS
7	INVISTA	1,206.61	--	1,206.61	MAN
8	O-N MINERALS COMPANY	4.15	1,004.24	1,008.39	MIN
9	WAYNESBORO, CITY OF	918.62	--	918.62	PWS
10	FRONT ROYAL, TOWN OF	--	881.20	881.20	PWS
11	ROCKINGHAM COUNTY	760.24	--	760.24	PWS
12	GEORGE'S CHICKEN LLC	611.61	--	611.61	MAN
13	DAYTON, TOWN OF	581.11	--	581.11	PWS
14	FOOD PROCESSORS WATER COOP	--	391.97	391.97	PWS
15	LURAY, TOWN OF	328.72	--	328.72	PWS
16	STRASBURG, TOWN OF	--	311.84	311.84	PWS
17	MILLERCOORS LLC.	307.98	--	307.98	MAN
18	BRIDGEWATER, TOWN OF	196.44	80.89	277.33	PWS
19	REYNOLDS PACKAGING LLC	275.60	--	275.60	MAN
20	WOODSTOCK, TOWN OF	--	238.55	238.55	PWS
21	MASSANUTTEN PUBLIC SERV CORP	232.42	--	232.42	PWS
22	NEW MARKET, TOWN OF	230.32	--	230.32	PWS
23	ELKTON, TOWN OF	220.78	--	220.78	PWS
24	BOWMAN APPLE PRODUCTS CO INC	187.41	--	187.41	MAN
25	STANLEY, TOWN OF	181.56	--	181.56	PWS
26	BROADWAY, TOWN OF	--	165.44	165.44	PWS
27	BERRYVILLE, TOWN OF	--	148.32	148.32	PWS
28	FRED G. SMITH	30.00	92.00	122.00	IRR
29	W A SHIFLETT	--	120.00	120.00	IRR
30	SHENANDOAH, TOWN OF	119.79	--	119.79	PWS
31	PHILIP WITMER	--	117.22	117.22	IRR
32	AQUA VA - DIV OF AQUA AMERICA	114.08	--	114.08	PWS
33	MOUNT JACKSON, TOWN OF	112.01	--	112.01	PWS
34	TIMBERVILLE, TOWN OF	86.56	--	86.56	PWS
35	GERALD HEATWOLE	--	82.90	82.90	AGR + IRR
36	GROTTOES, TOWN OF	78.27	--	78.27	PWS
37	WILLIAM B PATTERSON & SON	--	74.70	74.70	IRR
38	JOSEPH AND WAYNE WILKINS	--	64.10	64.10	IRR
39	STONE CREEK SANITARY DISTRICT	60.77	--	60.77	PWS
40	LYNN BRUBAKER	--	58.50	58.50	IRR
41	THOMAS S KEGLEY	--	57.20	57.20	IRR
42	LLOYD LEE MC PHERSON	--	50.25	50.25	AGR
43	MOORE AND DORSEY INC	46.80	--	46.80	IRR
44	GERALD W GARBER	7.30	38.80	46.10	IRR
45	UNITED STATES GOVERNMENT	--	44.31	44.31	PWS
46	BRYCE RESORT	--	43.51	43.51	COM
47	DANIEL A HOLSINGER	--	41.18	41.18	IRR
48	TOMS BROOK-MAURERTOWN SD	40.61	--	40.61	PWS
49	NOAH L RODES AND SONS	0.00	40.50	40.50	IRR
50	CLARKE COUNTY SANITATION AUTH	38.05	--	38.05	PWS
51	FEDERAL MOGUL CORPORATION	35.71	--	35.71	MAN
52	SHENVALEE LODGE INC	--	35.00	35.00	COM
53	OAKLAND FARMS, INC.	--	32.40	32.40	IRR
54	VALLEY PROTEINS INC	31.20	--	31.20	MAN
CONTINUED NEXT PAGE					

Appendix 1: Reported water withdrawals by owner in the Shenandoah Valley in 2010. Continued on next page. MG = Million Gallons, MAN = Manufacturing, PWS = Public Water System, COM = Commercial, IRR = Irrigation, MIN = Mining, AGR = Agriculture.

CONTINUED FROM PREVIOUS PAGE					
RANK	OWNER	REPORTED GROUND WATER USE (MG)	REPORTED SURFACE WATER USE (MG)	TOTAL 2010 REPORTED WATER USE (MG)	CATEGORY
55	WINCHESTER GOLF CLUB	--	29.50	29.50	IRR
56	SHRECKHISE BROTHERS INC	24.79	4.68	29.48	IRR
57	CHARLES M CLINE JR	--	28.20	28.20	IRR
58	COUNTRY CLUB OF STAUNTON	--	26.25	26.25	COM
59	WAYNESBORO COUNTRY CLUB, INC	26.03	--	26.03	COM
60	ROY E. MCDONALD	24.00	--	24.00	IRR
61	SHENANDOAH CLUB PROPERTIES	23.80	--	23.80	AGR
62	SPOTSWOOD COUNTRY CLUB, INC	11.48	12.18	23.66	COM
63	EDINBURG, TOWN OF	22.45	--	22.45	PWS
64	HIGH KNOB UTILITES INC	22.26	--	22.26	PWS
65	STEVE W CRAUN	--	21.00	21.00	IRR
66	LEON F. ROHRER	--	20.70	20.70	IRR
67	JAMES E WENGER	--	19.70	19.70	IRR
68	NOAH TURNER	--	19.40	19.40	IRR
69	NORMAN SHOWALTER	--	19.10	19.10	IRR
70	VIRGINIA, COMMONWEALTH OF	6.28	11.50	17.78	IRR + COM
71	BOWLING GREEN COUNTRY CLUB	17.50	--	17.50	COM
72	MENNO B. HORST	--	16.75	16.75	IRR
73	GALEN L WENGER	--	16.56	16.56	IRR
74	LURAY CAVERNS COUNTRY CLUB	--	16.33	16.33	COM
75	VALLEY MILK PRODUCTS	16.07	--	16.07	MAN
76	DIETRICH AND HELGA WESTPHAL	--	15.30	15.30	IRR
77	INGLESIDE HOTEL	13.36	--	13.36	COM
78	LEROY E HEATWOLE	--	12.60	12.60	IRR
79	DOUGLAS M. ATWOOD	11.99	--	11.99	IRR
80	JAMES L. WILL AND SONS	--	11.88	11.88	IRR
81	SHRINE MONT INC	9.83	--	9.83	COM
82	UNIMIN CORPORATION	9.52	0.00	9.52	MIN
83	ALLEN L SHANK	--	8.97	8.97	IRR
84	WELDON L. HEATWOLE	--	8.21	8.21	IRR
85	MRS. EMMA LOU SHOWALTER	--	7.80	7.80	IRR
86	MATHIAS BROTHERS, INC.	--	5.70	5.70	IRR
87	VALLEY WATER & UTILITIES	5.39	--	5.39	PWS
88	MARK AND DANIEL FLORA	--	5.23	5.23	IRR
89	THOMAS R. FLEMING	--	5.20	5.20	IRR
90	MATHIAS BROTHERS INC	5.20	--	5.20	IRR
91	DANIEL H BENDER	--	5.13	5.13	IRR
92	HOWELL METAL COMPANY	4.90	--	4.90	MAN
93	WILLIAM D. KITE	--	4.76	4.76	IRR
94	AUGUSTA LUMBER LLC	--	4.14	4.14	MAN
95	ROGER L & LINDA F MARTIN	--	4.00	4.00	IRR
96	PHILIP R WENGER	--	3.70	3.70	IRR
97	WILLIAM A ZIRKLE	--	3.60	3.60	IRR
98	STAN QUILLEN JR	3.05	--	3.05	IRR
99	DUNGADIN CIVIC CORPORATION	2.35	--	2.35	PWS
100	BERTELSMANN ARVATO	0.97	--	0.97	MAN

Appendix 1: Reported water use by owner in the Shenandoah Valley in 2010.

MG = Million Gallons, MAN = Manufacturing, PWS = Public Water System,

COM = Commercial, IRR = Irrigation, MIN = Mining.

APPENDIX 2

POPULATION DATA

POPULATION ESTIMATES (per capita)												
Year	Augusta County	Clarke County	Frederick County	Page County	Rockingham County	Shenandoah County	Warren County	City of Harrisonburg	City of Staunton	City of Waynesboro	City of Winchester	Total Shenandoah Valley
1990	54,557	12,101	45,723	21,690	57,482	31,636	26,142	30,707	24,581	18,549	21,947	345,115
1991	55,783	11,933	47,603	21,989	58,977	32,115	27,058	31,944	24,612	18,715	22,224	352,953
1992	56,735	11,917	48,660	22,247	60,177	32,211	27,806	32,910	24,639	18,693	22,460	358,455
1993	57,873	11,962	49,826	22,351	61,556	32,548	28,316	33,777	24,677	18,613	22,831	364,330
1994	59,043	11,972	51,224	22,434	62,865	32,644	28,854	34,766	24,616	18,604	23,317	370,339
1995	60,358	12,243	53,362	22,636	64,746	33,080	29,428	35,265	24,488	18,851	22,728	377,185
1996	61,613	12,302	54,727	22,847	66,222	33,124	30,148	36,430	24,245	19,136	22,771	383,565
1997	62,585	12,480	55,674	22,879	66,924	33,740	30,304	37,294	24,118	19,285	23,218	388,501
1998	63,591	12,436	57,010	23,105	67,307	34,248	30,471	38,205	24,167	19,121	23,350	393,011
1999	64,847	12,535	58,011	23,154	68,094	34,639	31,091	39,217	23,983	19,320	23,522	398,413
2000	65,385	12,638	59,226	23,151	67,825	35,068	31,553	40,390	23,951	19,617	23,599	402,403
2001	66,124	12,862	61,360	23,171	68,671	35,835	32,222	41,646	23,734	19,744	24,224	409,593
2002	66,735	12,950	63,313	23,265	69,315	36,525	33,031	42,837	23,691	20,010	24,602	416,274
2003	67,660	13,110	65,379	23,531	69,975	37,309	33,797	43,176	23,726	20,163	24,649	422,475
2004	68,899	13,413	67,442	23,527	70,789	38,272	34,434	43,753	23,501	20,351	25,175	429,556
2005	69,949	13,710	69,921	23,708	72,030	39,406	35,405	44,572	23,603	20,533	25,565	438,402
2006	71,896	13,939	72,456	24,045	73,000	40,610	36,231	45,858	23,638	20,728	25,757	448,158
2007	73,041	13,969	74,670	24,222	74,274	41,214	36,814	46,551	23,920	20,747	25,701	455,123
2008	73,555	14,092	76,060	24,208	75,075	41,720	37,259	47,286	23,945	20,920	26,004	460,124
2009	73,844	14,015	77,477	24,076	75,850	41,743	37,240	48,294	23,764	20,985	26,036	463,324
2010	73,750	14,034	78,305	24,042	76,314	41,993	37,575	48,914	23,746	21,006	26,203	465,882

Appendix 2a: Population estimates and census data for the Shenandoah Valley (per capita)

% of Population Supplied by Municipality or Commercial in 1990										
Augusta County	Clarke County	Frederick County	Page County	Rockingham County	Shenandoah County	Warren County	City of Harrisonburg	City of Staunton	City of Waynesboro	City of Winchester
45.5	37.6	44.7	48.5	34.3	47.4	48.7	97.3	99.2	98.9	98.7

Appendix 2b: Percentage of Population for various regions of the Shenandoah Valley that obtain water from a municipal or commercial source

APPENDIX 3

LIVESTOCK DATA

Year	Livestock Type	Reported Livestock Populations (Head)							
		Augusta County	Clarke County	Frederick County	Page County	Rockingham County	Shenandoah County	Warren County	Shenandoah Valley Total
1982	Dairy Cows	11,693	2,614	1,108	1,150	23,847	3,760	99	44,271
	All Cattle	99,740	19,279	23,316	22,178	118,729	38,739	10,259	332,240
	Hogs and Pigs	52,724	4,750	7,453	13,461	50,291	21,268	965	150,912
	Chickens	277,418	366	181	2,703,477	8,211,290	1,087,153	D	12,279,885
	Pullets	68,176	D	195	94,008	325,563	D	D	487,942
	Layers	202,528	D	106,445	D	898,813	290,338	D	1,498,124
	Turkeys	506,188	D	53	D	2,374,241	677,042	D	3,557,524
1987	Dairy Cows	12,467	1,943	786	906	24,499	3,391	D	43,992
	All Cattle	94,601	18,946	17,799	22,044	102,081	32,066	7,716	295,253
	Hogs and Pigs	23,265	3,870	4,765	8,773	58,971	14,975	2,004	116,623
	Chickens	276,114	0	28	3,703,550	9,913,390	1,272,380	D	15,165,462
	Pullets	70,872	D	220	16,440	702,647	84,603	D	874,782
	Layers	289,228	D	D	150,113	1,326,168	208,260	D	1,973,769
	Turkeys	870,831	D	30	111,216	2,884,167	382,518	6	4,248,762
1992	Dairy Cows	12,056	2,028	758	702	25,125	2,535	89	43,293
	All Cattle	105,262	18,847	19,078	24,617	112,921	34,924	8,467	324,116
	Hogs and Pigs	11,937	3,715	4,580	7,650	36,080	7,429	386	71,777
	Chickens	939,599	D	D	6,176,675	12,295,840	2,262,824	D	21,674,938
	Pullets	D	D	134	170,552	205,144	64,500	D	440,196
	Layers	332,790	256	D	461,098	1,669,929	69,226	D	2,533,299
	Turkeys	1,590,173	D	31	214,217	4,294,329	417,754	D	6,516,504
1997	Dairy Cows	10,234	1,105	716	444	25,477	2,701	121	40,798
	All Cattle	102,641	17,277	18,234	26,673	111,984	35,649	9,219	321,677
	Hogs and Pigs	1,762	2,711	3,950	9,668	13,865	5,497	84	37,537
	Chickens	911,027	D	38	7,209,771	17,491,765	2,686,813	D	28,299,414
	Pullets	D	D	73	119,159	313,620	D	D	432,852
	Layers	216,053	D	714	476,973	1,929,828	139,245	213	2,763,026
	Turkeys	2,206,387	D	D	595,000	3,870,344	942,005	D	7,613,736
2002	Dairy Cows	9,501	1,419	693	252	30,084	2,256	3	44,208
	All Cattle	104,914	16,887	20,113	23,418	119,938	38,317	8,788	332,375
	Hogs and Pigs	411	212	D	5,658	6,084	4,220	60	16,645
	Chickens	1,820,612	D	16	7,365,503	16,751,524	3,361,692	D	29,299,347
	Pullets	91,214	83	143	147,144	538,741	78,122	D	855,447
	Layers	88,863	667	1,225	264,624	804,025	D	82	1,159,486
	Turkeys	2,037,700	3	D	735,193	3,280,263	496,945	D	6,550,101
2007	Dairy Cows	7,930	1,860	432	285	24,014	2,549	4	37,074
	All Cattle	100,808	14,905	15,164	22,958	116,190	40,641	8,688	319,354
	Hogs and Pigs	1,283	1,127	D	4,074	3,373	10,107	171	20,135
	Chickens	2,581,789	52	321	7,015,010	13,437,255	3,386,070	D	26,420,497
	Pullets	123,618	125	48	139,000	415,761	82,212	138	760,902
	Layers	107,546	791	1,265	248,956	1,101,858	58,092	768	1,519,276
	Turkeys	1,509,581	28	9	902,211	3,046,414	435,642	D	5,893,885

Appendix 3a: Estimated livestock populations by county in the Shenandoah Valley.

(Collated from: NASS, 2009; NASS 1999, NASS 1990).

D = Data withheld by USDA to avoid disclosing data for individual farms.

Type of Livestock	1	2	3	4	5	Rates Used in This Report
	gal/day	gal/day	gal/day	gal/day	gal/day	gal/day
Beef Cows (per head)	12	12	-	12	6.6 - 16	12
Milk Cows (per head)	110	20	45	16	18 - 65	40
Turkeys (per 1000 head)	17	170	-	-	50-220	100
Chickens (1000 head)	54*	68	-	-	20-120	60
Hogs and Pigs (per head)	-	-	-	2.5	2 - 8.1	3.5
1 = VDEQ Agricultural Program, pers comm. 2 = USDA - Harrisonburg Extension Office, pers comm. 3 = Gay, 2009 4 = Lardy and Stoltenow, 1999 5 = Lovelace, 2009 *Data from metered poultry houses in Rockingham County						

Appendix 3b: Livestock water use coefficients used in this report.

APPENDIX 4

2007 SURFACE WATER WITHDRAWAL DATA

2007 Surface Water Use (MG)	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	WATERSHED
3108.59	WINCHESTER, CITY OF	PWS	STREAM/RIVER	3859X07817X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH RIVER
1355.36	HARRISONBURG, CITY OF	PWS	STREAM/RIVER	3822X07858X01	38.XXXX	-78.XXXX	M	NORTH RIVER / DRY RIVER
1145.04	HARRISONBURG, CITY OF	PWS	STREAM/RIVER	3831X07903X01	38.XXXX	-79.XXXX	M	NORTH RIVER / DRY RIVER
827.73	FRONT ROYAL, TOWN OF	PWS	STREAM/RIVER	3854X07812X01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH RIVER
793.57	AUTHORITY	PWS	RESERVOIR	3915X07805X01	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK
585.66	AUTHORITY	PWS	RESERVOIR	3905X07813X01	39.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH RIVER
583.98	STAUNTON, CITY OF	PWS	RESERVOIR	3819X07912X01	38.XXXX	-79.XXXX	M	NORTH RIVER / DRY RIVER
360.01	FOOD PROCESSORS WATER COOP	PWS	STREAM/RIVER	3837X07846X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH RIVER
310.00	STRASBURG, TOWN OF	PWS	STREAM/RIVER	3859X07822X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH RIVER
301.00	VIRGINIA, COMMONWEALTH OF	AGR	STREAM/RIVER	385700078173001	38.950000000	-78.291666667	E	PASSAGE CREEK
270.82	WOODSTOCK, TOWN OF	PWS	STREAM/RIVER	3851X07830X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH RIVER
175.50	W A SHIFLETT	IRR	STREAM/RIVER	381335078543001	38.226388889	-78.908333333	E	MIDDLE RIVER/CHRISTIANS CREEK
149.80	BERRYVILLE, TOWN OF	PWS	STREAM/RIVER	3906X07755X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH RIVER
144.07	AUGUSTA COUNTY SERVICE AUTH	PWS	RESERVOIR	3801X07858X01	38.XXXX	-78.XXXX	M	SOUTH RIVER
119.00	BROADWAY, TOWN OF	PWS	STREAM/RIVER	3837X07847X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH RIVER
73.10	BRYCE RESORT	COM	STREAM/RIVER	384905078460201	38.818055556	-78.767222222	M	NORTH FORK SHENANDOAH RIVER
62.40	LOWELL D HEATWOLE	IRR	STREAM/RIVER	A5697	N/A	N/A	E	NORTH RIVER / DRY RIVER
46.60	GERALD W GARBER	IRR	STREAM/RIVER	381743078523601	38.295277778	-78.876666667	E	NORTH RIVER / DRY RIVER
44.15	SHENVALEE LODGE INC	COM	STREAM/RIVER	383807078394701	38.635277778	-78.663055556	M	NORTH FORK SHENANDOAH RIVER
35.03	HARRISONBURG, CITY OF	COM	RESERVOIR	382649078534801	38.446944444	-78.896666667	M	NORTH RIVER / DRY RIVER
32.90	WILLIAM B PATTERSON & SON	IRR	STREAM/RIVER	381039078511101	38.177500000	-78.853055556	E	SOUTH RIVER
32.19	BRIDGEWATER, TOWN OF	PWS	STREAM/RIVER	3823X07859X01	38.XXXX	-78.XXXX	M	NORTH RIVER / DRY RIVER
31.30	WINCHESTER GOLF CLUB	IRR	STREAM/RIVER	391017078083101	39.171388889	-78.141944444	M	OPEQUON/BACK CREEK
29.00	LLOYD LEE MC PHERSON	AGR	STREAM/RIVER	380209079054501	38.036500000	-79.093830000	E	MIDDLE RIVER/CHRISTIANS CREEK
27.18	DANIEL A HOLSINGER	IRR	STREAM/RIVER	380820078514201	38.138888889	-78.861666667	E	SOUTH RIVER
25.71	UNITED STATES GOVERNMENT	PWS	STREAM/RIVER	3905X07754X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH RIVER
22.00	SPOTSWOOD COUNTRY CLUB, INC	COM	RESERVOIR	382558078500801	38.432777778	-78.835555556	M	NORTH RIVER / DRY RIVER
21.75	LLOYD LEE MC PHERSON	IRR	STREAM/RIVER	380209079054502	38.030080000	-79.107170000	E	MIDDLE RIVER/CHRISTIANS CREEK
21.60	SOUTH RIVER STONE, LLC.	MIN	STREAM/RIVER	381911078445101	38.319722222	-78.747500000	E	SOUTH FORK SHENANDOAH RIVER
21.60	JAMES L. WILL AND SONS	IRR	STREAM/RIVER	382200079011501	38.366666667	-79.020833333	E	NORTH RIVER / DRY RIVER
21.44	LURAY CAVERNS COUNTRY CLUB	COM	STREAM/RIVER	384033078304701	38.675833333	-78.513055556	M	SOUTH FORK SHENANDOAH RIVER
19.90	DIETRICH AND HELGA WESTPHAL	IRR	RESERVOIR	390559078002801	39.099722222	-78.007777778	E	MAIN STEM SHENANDOAH RIVER
18.00	WELDON L. HEATWOLE	IRR	STREAM/RIVER	382326078375001	38.390555556	-78.630555556	E	SOUTH FORK SHENANDOAH RIVER
16.50	COUNTRY CLUB OF STAUNTON	COM	STREAM/RIVER	381007079010301	38.168611111	-79.017500000	E	MIDDLE RIVER/CHRISTIANS CREEK
15.90	OAKLAND FARMS, INC.	IRR	STREAM/RIVER	381642078511601	38.278333333	-78.854444444	E	NORTH RIVER / DRY RIVER
14.47	LAKEVIEW DEVELOPMENT CORP	COM	RESERVOIR	382317078500801	38.392431936	-78.815586328	M	SOUTH FORK SHENANDOAH RIVER
13.50	CLIFFORD A WENGER	IRR	STREAM/RIVER	382431078562201	38.408611111	-78.939444444	E	NORTH RIVER / DRY RIVER
12.00	VIRGINIA, COMMONWEALTH OF	IRR	STREAM/RIVER	A5496	38.180000000	78.850000000	E	SOUTH RIVER

Appendix 4: Reported surface water withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons
M = Measured, E = Estimated. XX = data withheld for security purposes. N/A = Location unknown. (Table continued on next page).

2007 Surface Water Use (MG)	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	WATERSHED
12.00	LEROY E HEATWOLE	IRR	STREAM/RIVER	382326078375001	38.390555556	-78.630555556	E	SOUTH FORK SHENANDOAH RIVER
11.30	JOSEPH AND WAYNE WILKINS	IRR	STREAM/RIVER	384234078383801	38.709444444	-78.643888889	E	NORTH FORK SHENANDOAH RIVER
11.10	JOSEPH AND WAYNE WILKINS	IRR	STREAM/RIVER	384129078394901	N/A	N/A	E	NORTH FORK SHENANDOAH RIVER
11.00	DAVID W QUILLEN	IRR	STREAM/RIVER	380206078573301	38.035000000	-78.959166667	M	SOUTH RIVER
10.60	O-N MINERALS COMPANY	MAN	RESERVOIR	390100078200002	39.016055000	-78.327515000	E	NORTH FORK SHENANDOAH RIVER
10.50	ALLEN L SHANK	IRR	STREAM/RIVER	382422079024301	38.406111111	-79.045277778	E	NORTH RIVER / DRY RIVER
10.25	MILLARD DRIVER	IRR	RESERVOIR	381018078562101	38.171666667	-78.939166667	E	MIDDLE RIVER/CHRISTIANS CREEK
10.00	DAVID W QUILLEN	IRR	STREAM/RIVER	380213078555102	N/A	N/A	E	SOUTH RIVER
9.80	MRS. EMMA LOU SHOWALTER	IRR	STREAM/RIVER	382410078563501	N/A	N/A	E	NORTH RIVER / DRY RIVER
9.00	LEROY E HEATWOLE	IRR	STREAM/RIVER	382416078380201	38.404444444	-78.633888889	E	SOUTH FORK SHENANDOAH RIVER
7.38	GALEN L WENGER	IRR	STREAM/RIVER	382431078562301	38.408611111	-78.939722222	E	NORTH RIVER / DRY RIVER
6.75	AUGUSTA LUMBER LLC	MAN	STREAM/RIVER	380433078525601	38.075833333	-78.882222222	M	SOUTH RIVER
6.20	MILLARD DRIVER	IRR	STREAM/RIVER	381020078555601	38.172222222	-78.932222222	E	MIDDLE RIVER/CHRISTIANS CREEK
6.00	DAVID W QUILLEN	IRR	STREAM/RIVER	380115078584501	38.020833333	-78.979166667	M	SOUTH RIVER
6.00	PHILIP R WENGER	IRR	STREAM/RIVER	382743078584401	38.461944444	-78.978888889	E	NORTH RIVER / DRY RIVER
6.00	DARYL W HEATWOLE	IRR	STREAM/RIVER	382105078565101	38.351388889	-78.947500000	E	NORTH RIVER / DRY RIVER
5.70	SHRECKHISE BROTHERS INC	IRR	STREAM/RIVER	380649078514801	38.113611111	-78.863333333	E	SOUTH RIVER
5.50	DAVID W QUILLEN	IRR	STREAM/RIVER	D5097	N/A	N/A	E	OPEQUON/BACK CREEK
5.27	DANIEL H BENDER	IRR	STREAM/RIVER	383910078414901	38.652777778	-78.696944444	E	NORTH FORK SHENANDOAH RIVER
5.10	NOAH TURNER	IRR	STREAM/RIVER	383459078290101	38.583055556	-78.483611111	E	SOUTH FORK SHENANDOAH RIVER
4.86	LYNN BRUBAKER	IRR	STREAM/RIVER	382755079003601	38.465277778	-79.010000000	E	NORTH RIVER / DRY RIVER
4.60	WELDON L. HEATWOLE	IRR	STREAM/RIVER	382416078380201	38.404444444	-78.633888889	E	SOUTH FORK SHENANDOAH RIVER
4.00	LEON F. ROHRER	IRR	STREAM/RIVER	382520078562401	38.422222222	-78.940000000	E	NORTH RIVER / DRY RIVER
4.00	LEON F. ROHRER	IRR	RESERVOIR	382530078562801	38.425000000	-78.941111111	E	NORTH RIVER / DRY RIVER
2.25	ROGER L & LINDA F MARTIN	IRR	STREAM/RIVER	383945078405501	38.662500000	-78.681944444	E	NORTH FORK SHENANDOAH RIVER
2.00	NATHAN RAY HORST	IRR	STREAM/RIVER	381555078514801	38.265277778	-78.863333333	E	MIDDLE RIVER/CHRISTIANS CREEK
1.54	ANDRE VIETTE	IRR	STREAM/RIVER	380815078561801	38.137500000	-78.938333333	M	MIDDLE RIVER/CHRISTIANS CREEK
1.10	WILLIAM B PATTERSON & SON	IRR	STREAM/RIVER	381039078511102	38.177500000	-78.853055556	E	SOUTH RIVER
0.50	WILLIAM B PATTERSON & SON	IRR	STREAM/RIVER	381047078511701	38.179722222	-78.854722222	E	SOUTH RIVER
0.08	NORMAN SHOWALTER	IRR	STREAM/RIVER	382437078583601	38.410277778	-78.976666667	M	NORTH RIVER / DRY RIVER
0.01	WILLIAM A ZIRKLE	IRR	STREAM/RIVER	384014078384601	38.670555556	-78.646111111	M	NORTH FORK SHENANDOAH RIVER

Appendix 4: Reported surface water withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons

M = Measured, E = Estimated. XX = data withheld for security purposes. N/A = Location unknown. (Table continued from previous page).

APPENDIX 5

2007 GROUNDWATER WITHDRAWAL DATA

2007 Ground Water Use (MG)	DEQ Well Number	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	River Watershed	Geologic Unit
990.31	107-00085	STAUNTON, CITY OF	PWS	SPRING	3813XX07906XX01	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	EDINBURG, LINCOLNSHIRE, NEW MARKET
602.80	182-01094	MERCK & CO	MAN	WELL	382324078390202	38.3811880	-78.6419730	M	SOUTH FORK SHENANDOAH	ROME, WAYNESBORO, SHADY, TOMSTOWN
589.70	107-00449	WAYNESBORO, CITY OF	PWS	WELL	3823XX07839XX02	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
542.80	107-01458	WAYNESBORO, CITY OF	PWS	WELL	3803XX07854XX01	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
528.18	107-00451	INVISTA	MAN	WELL	380347078525301	38.0630560	-78.8813890	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
481.10	182-00313	MERCK & CO	MAN	WELL	382325078391501	38.3891450	-78.6535210	M	SOUTH FORK SHENANDOAH	ELBROOK
398.58	182-01106	MILLERCOORS LLC.	MAN	WELL	382134078411501	38.3608560	-78.6830860	M	SOUTH FORK SHENANDOAH	ELBROOK
359.94	182-01096	ROCKINGHAM COUNTY	PWS	WELL	3822XX07843XX01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ELBROOK
347.64	107-00002	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3800XX07901XX01	38.XXXX	-79.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
345.15	134-00322	FCSA	PWS	WELL	3915XX07804XX01	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	EDINBURG, LINCOLNSHIRE, NEW MARKET
342.62	182-01097	ROCKINGHAM COUNTY	PWS	WELL	3820XX07844XX01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ELBROOK
316.35	107-00453	INVISTA	MAN	SPRING	380328078533701	38.0577780	-78.8936110	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
298.80	182-00189	MERCK & CO	MAN	WELL	382307078390101	38.3856600	-78.6505650	M	SOUTH FORK SHENANDOAH	ELBROOK
288.50	182-01100	BRIDGEWATER, TOWN OF	PWS	WELL	3823XX07859XX02	38.XXXX	-78.XXXX	M	NORTH RIVER/DRY RIVER	BEEKMANTOWN
282.49	182-01105	MILLERCOORS LLC.	MAN	WELL	382051078414001	38.3549670	-78.6790590	M	SOUTH FORK SHENANDOAH	ROME, WAYNESBORO, SHADY, TOMSTOWN
277.37	107-00048	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3800XX07857XX01	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
259.90	182-00190	MERCK & CO	MAN	WELL	382301078391001	38.3837210	-78.6526780	M	SOUTH FORK SHENANDOAH	ELBROOK
255.80	107-00099	REYNOLDS PACKAGING LLC	MAN	WELL	381524078493501	38.2566670	-78.8263890	M	SOUTH RIVER	ELBROOK
235.80	182-00127	MERCK & CO	MAN	WELL	382302078390401	38.3840400	-78.6516490	M	SOUTH FORK SHENANDOAH	ELBROOK
226.28	182-01115	DAYTON, TOWN OF	PWS	WELL	3825XX07856XX01	38.XXXX	-78.XXXX	M	NORTH RIVER/DRY RIVER	BEEKMANTOWN
223.15	182-01101	DAYTON, TOWN OF	PWS	WELL	3824XX07857XX01	38.XXXX	-78.XXXX	M	NORTH RIVER/DRY RIVER	EDINBURG, LINCOLNSHIRE, NEW MARKET
212.60	182-00078	MERCK & CO	MAN	WELL	382322078390001	38.3895820	-78.6512670	M	SOUTH FORK SHENANDOAH	ELBROOK
212.60	182-00191	MERCK & CO	MAN	WELL	382323078390401	38.3895630	-78.6513390	M	SOUTH FORK SHENANDOAH	ELBROOK
210.00	182-01093	MERCK & CO	MAN	WELL	382324078390201	38.3882580	-78.6571620	M	SOUTH FORK SHENANDOAH	ELBROOK
201.06	134-00338	FCSA	PWS	WELL	3915XX07805XX02	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	EDINBURG, LINCOLNSHIRE, NEW MARKET
191.23	169-00067	LURAY, TOWN OF	PWS	SPRING	3840XX07825XX01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHIEAGUE
189.22	185-00029	GEORGE'S CHICKEN LLC	MAN	WELL	385225078373001	38.8756660	-78.6248670	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
188.44	107-00130	INVISTA	MAN	WELL	380351078530401	38.0641670	-78.8844440	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
175.30	182-00193	MERCK & CO	MAN	WELL	382322078390201	38.3895340	-78.6514390	M	SOUTH FORK SHENANDOAH	ELBROOK
162.85	107-00021	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3800XX07857XX02	38.XXXX	-79.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
141.80	182-00194	MERCK & CO	MAN	WELL	382322078385801	38.3896090	-78.6511930	M	SOUTH FORK SHENANDOAH	ELBROOK
137.06	107-00036	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3800XX07902XX01	38.XXXX	-79.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
132.94	182-00196	DAYTON, TOWN OF	PWS	SPRING	3825XX07856XX02	38.XXXX	-78.XXXX	M	NORTH RIVER/DRY RIVER	BEEKMANTOWN
120.99	185-00718	GEORGE'S CHICKEN LLC	MAN	WELL	385226078373602	38.8768210	-78.6270160	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
120.89	185-00717	GEORGE'S CHICKEN LLC	MAN	WELL	385226078373601	38.8757600	-78.6280870	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
116.70	182-00192	MERCK & CO	MAN	WELL	382322078390301	38.3895530	-78.6513730	M	SOUTH FORK SHENANDOAH	ELBROOK
111.65	182-00086	ELKTON, TOWN OF	PWS	WELL	3824XX07837XX01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ELBROOK
109.00	107-00100	REYNOLDS PACKAGING LLC	MAN	WELL	381518078493501	38.2550000	-78.8263890	M	SOUTH RIVER	ELBROOK
108.95	182-01111	MASSANUTTEN PUBLIC SERV CORP	PWS	WELL	3824XX07844XX01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	SILICICLASTIC
105.12	185-00432	GEORGE'S CHICKEN LLC	MAN	WELL	385235078373501	38.8767520	-78.6263950	M	NORTH FORK SHENANDOAH	BEEKMANTOWN

Appendix 5a: Reported groundwater withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons
M = Measured, E = Estimated. XX = data withheld for security purposes. (Table cont'd next page)

2007 Ground Water Use (MG)	DEQ Well Number	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	River Watershed	Geologic Unit
104.19	182-00504	MASSANUTTEN PUBLIC SERV CORP	PWS	WELL	3824X007844X001	38.XXXX	-78.XXXX	M	SOUTH FORK	SILICICLASTIC
101.80	107-00101	REYNOLDS PACKAGING LLC	MAN	WELL	381521078493901	38.2558330	-78.8275000	M	SOUTH RIVER	ELBROOK
97.65	185-00065	NEW MARKET, TOWN OF	PWS	WELL	3839X007841X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
92.40	107-00408	INVISTA	MAN	WELL	380331078531601	38.0586110	-78.8877780	M	SOUTH RIVER	SILICICLASTIC
88.18	185-00714	BOWMAN APPLE PRODUCTS CO INC	MAN	WELL	384552078371001	38.7647140	-78.6193310	M	NORTH FORK SHENANDOAH	CONOCOCHAGUE
85.31	169-00070	LURAY, TOWN OF	PWS	SPRING	3839X007828X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHAGUE
83.86	169-00128	STANLEY, TOWN OF	PWS	WELL	3834X007829X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ELBROOK
75.07	169-00269	STANLEY, TOWN OF	PWS	WELL	3834X007830X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHAGUE
71.86	134-00382	VALLEY PROTEINS INC	MAN	WELL	391342078144001	39.2272220	-78.2429850	M	OPEQUON/BACK CREEK	SILICICLASTIC
62.38	107-00066	AUGUSTA COUNTY SERVICE AUTH	PWS	SPRING	3818X007855X001	38.XXXX	-78.XXXX	M	NORTH RIVER/DRY RIVER	CONOCOCHAGUE
59.00	107-00067	AUGUSTA COUNTY SERVICE AUTH	PWS	SPRING	3812X007902X001	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	CONOCOCHAGUE
57.08	185-00712	NEW MARKET, TOWN OF	PWS	WELL	3838X007841X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
56.16	185-00695	MOUNT JACKSON, TOWN OF	PWS	WELL	3844X0078525001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHAGUE
55.70	182-00131	TIMBERVILLE, TOWN OF	PWS	WELL	3837X007845X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
55.64	169-00293	SHENANDOAH, TOWN OF	PWS	WELL	3829X007836X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHAGUE
53.85	107-00233	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3807X007850X001	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
51.14	169-00207	SHENANDOAH, TOWN OF	PWS	WELL	3828X007836X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHAGUE
50.50	134-00011	FEDERAL MOGUL CORPORATION	MAN	WELL	390927078103301	39.1575000	-78.1758300	E	OPEQUON/BACK CREEK	BEEKMANTOWN
50.26	185-00671	NEW MARKET, TOWN OF	PWS	WELL	3838X007841X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
49.60	107-00409	INVISTA	MAN	WELL	380341078525501	38.0613890	-78.8819440	M	SOUTH RIVER	SILICICLASTIC
47.15	182-00507	GROTTOES, TOWN OF	PWS	WELL	3815X007848X001	38.XXXX	-78.XXXX	M	SOUTH RIVER	ELBROOK
41.00	107-00784	DAVID W QUILLEN	IRR	WELL	380218078565801	38.0380730	-78.9490500	M	SOUTH RIVER	ELBROOK
39.76	182-01112	MASSANUTTEN PUBLIC SERV CORP	PWS	WELL	3824X007843X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	SILICICLASTIC
39.34	185-00704	STONEY CREEK SANITARY DISTRICT	PWS	WELL	3849X007847X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
37.90	185-00713	NEW MARKET, TOWN OF	PWS	WELL	3838X007842X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
37.32	185-00079	GEORGE'S CHICKEN LLC	MAN	WELL	385230078374701	38.8756660	-78.6298910	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
35.92	134-00345	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3919X007818X004	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
32.93	185-00730	TOMS BROOK-MAURERTOWN SD	PWS	WELL	3856X007826X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
30.82	134-00384	VALLEY PROTEINS INC	MAN	WELL	391336078140601	39.2267810	-78.2447290	M	OPEQUON/BACK CREEK	SILICICLASTIC
30.18	121-00150	CLARKE COUNTY SANITATION AUTH	PWS	SPRING	3905X007802X001	39.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	CONOCOCHAGUE
29.60	182-00130	TIMBERVILLE, TOWN OF	PWS	SPRING	3840X007848X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
28.85	107-00169	WAYNESBORO COUNTRY CLUB	COM	SPRING	380326078551601	38.0572220	-78.9211110	U	SOUTH RIVER	ELBROOK
28.53	185-00008	EDINBURG, TOWN OF	PWS	WELL	3849X007833X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
27.00	193-00238	BOWLING GREEN COUNTRY CLUB	COM	WELL	385945078072501	38.9806860	-78.1292190	M	MAIN STEM SHENANDOAH	ELBROOK
26.97	182-00073	GROTTOES, TOWN OF	PWS	WELL	3815X007848X001	38.XXXX	-78.XXXX	M	SOUTH RIVER	ELBROOK
26.15	134-00343	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3919X007818X003	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
24.60	107-01027	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X007913X001	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	CONOCOCHAGUE
23.93	134-00288	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3918X007818X001	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
22.39	185-00696	MOUNT JACKSON, TOWN OF	PWS	WELL	3844X007837X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
22.19	185-00050	TOMS BROOK-MAURERTOWN SD	PWS	WELL	3857X007827X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHAGUE
21.92	182-01117	SHRECKHISE BROTHERS INC	IRR	WELL	381640078492901	38.2621520	-78.8253410	E	SOUTH RIVER	ELBROOK

Appendix 5a: Reported groundwater withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons
M = Measured, E = Estimated. XX = data withheld for security purposes. (Table cont'd next page)

2007 Ground Water Use (MG)	DEQ Well Number	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	River Watershed	Geologic Unit
21.11	185-00625	EDINBURG, TOWN OF	PWS	WELL	3849X007834X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
18.00	185-00734	JOHNS MANVILLE	MAN	SPRING	385046078321401	38.8458810	-78.5386560	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
17.84	134-00300	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3916X007818X001	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
16.60	193-00115	SHENANDOAH CLUB PROPERTIES	AGR	WELL	385940078074501	38.9944440	-78.1291670	M	MAIN STEM SHENANDOAH	CONOCOCHIEAGUE
16.54	185-00148	MOUNT JACKSON, TOWN OF	PWS	WELL	3845X007837X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
16.19	185-00702	STONEY CREEK SANITARY DISTRICT	PWS	WELL	3849X007845X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
14.89	107-00554	INGLESIDE HOTEL	IRR	WELL	381115079020901	38.1875000	-79.0358330	M	MIDDLE RIVER/CHRISTIANS CREEK	BEEKMANTOWN
14.60	121-00279	MOORE AND DORSEY INC	IRR	WELL	390955077560201	39.1649400	-77.9325190	M	MAIN STEM SHENANDOAH	ELBROOK
14.52	134-00349	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	BY0236	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
14.40	185-00726	O-N MINERALS COMPANY	MAN	WELL	390100078200001	39.0159540	-78.3339950	E	NORTH FORK SHENANDOAH	BEEKMANTOWN
13.25	169-00114	SHENANDOAH, TOWN OF	PWS	WELL	3829X007836X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHIEAGUE
12.67	182-00125	ELKTON, TOWN OF	PWS	SPRING	3824X007836X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ROME, WAYNESBORO, SHADY, TOMSTOWN
12.38	169-00024	STANLEY, TOWN OF	PWS	WELL	3834X007830X001	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	ELBROOK
12.00	134-00381	ROY E. MCDONALD	IRR	WELL	390439078153201	39.0767590	-78.2560310	E	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
12.00	182-00544	SPOTSWOOD COUNTRY CLUB, INC	COM	WELL	382548078501401	38.4298750	-78.8346960	E	NORTH RIVER/DRY RIVER	BEEKMANTOWN
11.88	134-00344	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3919X007818X002	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
11.48	185-00089	STONEY CREEK SANITARY DISTRICT	PWS	WELL	3849X007844X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
11.46	185-00034	BOWMAN APPLE PRODUCTS CO INC	MAN	WELL	384605078372601	38.7678740	-78.6228960	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
10.04	182-01125	LAKEVIEW DEVELOPMENT CORP	COM	WELL	382318078521001	38.3961150	-78.8164570	M	SOUTH FORK SHENANDOAH	BEEKMANTOWN
10.00	***	DAVID W QUILLEN	IRR	WELL	380218078565802	38.0028820	-78.9724420	E	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
10.00	182-00545	SPOTSWOOD COUNTRY CLUB, INC	COM	WELL	382548078500401	38.4298750	-78.8374740	E	NORTH RIVER/DRY RIVER	BEEKMANTOWN
10.00	107-01473	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X007913X001	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	SILICICLASTIC
9.51	185-00084	STONEY CREEK SANITARY DISTRICT	PWS	WELL	3848X007845X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
9.50	121-00282	MOORE AND DORSEY INC	IRR	WELL	G5030	39.1610800	-77.9381150	M	MAIN STEM SHENANDOAH	ELBROOK
9.47	134-00380	UNIMIN CORPORATION	MIN	WELL	391453078201602	39.2481310	-78.3383130	M	OPEQUON/BACK CREEK	SILICICLASTIC
9.34	185-00719	VALLEY MILK PRODUCTS	COM	WELL	395914078212301	38.9874720	-78.3563480	M	NORTH FORK SHENANDOAH	SILICICLASTIC
9.06	134-00342	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3919X007818X005	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
9.04	185-00092	MOUNT JACKSON, TOWN OF	PWS	WELL	3842X007839X001	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
9.01	182-01119	SHRECKHISE BROTHERS INC	IRR	WELL	381640078492902	38.2793110	-78.8240190	E	SOUTH RIVER	CONOCOCHIEAGUE
8.80	185-00068	O-N MINERALS COMPANY	MAN	WELL	390108078200001	39.0191980	-78.3333510	E	NORTH FORK SHENANDOAH	BEEKMANTOWN
8.01	134-00007	AQUA VA - AQUA LK HOLIDAY INC	PWS	WELL	3916X007818X001	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
7.87	134-00379	UNIMIN CORPORATION	MIN	WELL	391452078201601	39.2493390	-78.3362870	E	OPEQUON/BACK CREEK	SILICICLASTIC
7.07	169-00301	DOUGLAS M. ATWOOD	IRR	SPRING	383757078263901	38.6443990	-78.4511840	E	SOUTH FORK SHENANDOAH	ELBROOK
7.00	107-01495	GARLAND FLORY	IRR	SPRING	381322078535801	38.2227000	-78.8994400	E	MIDDLE RIVER/CHRISTIANS CREEK	SILICICLASTIC
6.36	182-00579	VALLEY PROTEINS INC	MAN	WELL	383217078495801	38.5380560	-78.8327780	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
5.93	193-00094	HIGH KNOB UTILITES INC	PWS	SPRING	3853X007806X001	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
5.50	107-00124	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X007849X001	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
4.87	107-00661	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X007849X001	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
4.54	185-00471	SHRINE MONT INC	COM	WELL	384741078491801	38.7947220	-78.8216670	M	NORTH FORK SHENANDOAH	SILICICLASTIC
4.47	182-00320	VALLEY PROTEINS INC	MAN	WELL	383223078495201	38.5327110	-78.8351410	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
4.40	107-00722	O-N MINERALS COMPANY	MAN	WELL	390108078200201	39.0191060	-78.3340030	E	NORTH FORK SHENANDOAH	BEEKMANTOWN

Appendix 5a: Reported groundwater withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons
M = Measured, E = Estimated. XX = data withheld for security purposes. *** well construction data not available (Table cont'd next page).

2007 Ground Water Use (MG)	DEQ Well Number	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	River Watershed	Geologic Unit
4.36	182-01122	ROCKINGHAM COUNTY	PWS	WELL	3827X007900X02	38.XXXX	-79.XXXX	M	NORTH RIVER/DRY RIVER	CONOCOCHIEAGUE
4.33	107-00017	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3808X007849X01	38.XXXX	-78.XXXX	M	SOUTH RIVER	ROME, WAYNESBORO, SHADY, TOMSTOWN
3.62	134-00348	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	BX0236	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
3.45	193-00245	HIGH KNOB UTILITIES INC	PWS	WELL	3854X007807X01	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
3.41	185-00655	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AX2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
3.05	193-00241	HIGH KNOB UTILITIES INC	PWS	WELL	3853X007806X02	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
3.02	185-00080	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AO2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
2.94	185-00720	VALLEY MILK PRODUCTS	COM	WELL	395915078212301	38.9874720	-78.3563290	M	NORTH FORK SHENANDOAH	SILICICLASTIC
2.87	107-01451	STAN QUILLEN JR	IRR	WELL	A5094	38.0754080	-78.9145430	M	SOUTH RIVER	ELBROOK
2.83	121-00288	SHENANDOAH RETREAT LAND CORP	PWS	WELL	3908X007751X02	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH	SILICICLASTIC
2.79	169-00028	VALLEY WATER & UTILITIES	PWS	WELL	3840X007826X01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	BEEKMANTOWN
2.75	107-01459	ANDRE VIETTE	IRR	WELL	C5091	38.1233240	-78.9444960	M	MIDDLE RIVER/CHRISTIANS CREEK	BEEKMANTOWN
2.66	182-01123	VIRGINIA, COMMONWEALTH OF	PWS	WELL	3831X007849X01	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
2.62	193-00092	DUNGADIN CIVIC CORPORATION	PWS	WELL	3853X007814X01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHIEAGUE
2.53	185-00127	HOWELL METAL COMPANY	MAN	WELL	383929078420801	38.6580560	-78.7022220	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
2.21	182-00120	VALLEY PROTEINS INC	MAN	WELL	383207078500001	38.5352780	-78.8333330	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
2.14	107-01460	ANDRE VIETTE	IRR	WELL	B5091	38.1311610	-78.9547670	M	MIDDLE RIVER/CHRISTIANS CREEK	SILICICLASTIC
1.98	107-01471	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X007912X01	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	CONOCOCHIEAGUE
1.96	107-00092	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3803X007913X01	38.XXXX	-79.XXXX	M	MIDDLE RIVER/CHRISTIANS CREEK	ELBROOK
1.88	121-00144	SHENANDOAH RETREAT LAND CORP	PWS	WELL	3908X007752X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH	SILICICLASTIC
1.82	193-00243	HIGH KNOB UTILITIES INC	PWS	WELL	3853X007806X01	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
1.78	134-00346	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	BV0236	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
1.72	193-00242	HIGH KNOB UTILITIES INC	PWS	WELL	3853X007806X03	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
1.53	134-00289	GARY W MCDONALD	IRR	SPRING	A5888	39.0639640	-78.2977830	E	NORTH FORK SHENANDOAH	BEEKMANTOWN
1.51	193-00240	HIGH KNOB UTILITIES INC	PWS	WELL	3853X007806X04	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
1.51	185-00099	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AP2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
1.50	185-00638	HOWELL METAL COMPANY	MAN	WELL	383930078420501	38.6583330	-78.7013890	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
1.50	121-00289	SHENANDOAH RETREAT LAND CORP	PWS	WELL	3907X007752X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH	SILICICLASTIC
1.50	182-00587	VALLEY PROTEINS INC	MAN	WELL	383241078500801	38.5368220	-78.8344190	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
1.30	182-00043	VIRGINIA, COMMONWEALTH OF	COM	WELL	383150078485801	38.5300220	-78.8153720	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
1.25	185-00660	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	BT2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	SILICICLASTIC
1.17	193-00246	DUNGADIN CIVIC CORPORATION	PWS	WELL	3853X007814X01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	IGNEOUS / METAMORPHIC
1.15	121-00007	SHENANDOAH RETREAT LAND CORP	PWS	WELL	3907X007752X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH	SILICICLASTIC
1.13	193-00093	HIGH KNOB UTILITIES INC	PWS	SPRING	3853X007807X01	38.XXXX	-78.XXXX	E	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
1.11	193-00239	HIGH KNOB UTILITIES INC	PWS	WELL	3854X007807X02	38.XXXX	-78.XXXX	M	MAIN STEM SHENANDOAH	IGNEOUS / METAMORPHIC
1.10	185-00270	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AE2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
1.05	185-00088	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AV2246	38.XXXX	-78.XXXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
1.01	107-01461	ANDRE VIETTE	IRR	WELL	A5091	38.1320410	-78.9573550	M	MIDDLE RIVER/CHRISTIANS CREEK	SILICICLASTIC
0.97	121-00146	SHENANDOAH RETREAT LAND CORP	PWS	WELL	3907X007751X01	39.XXXX	-77.XXXX	M	MAIN STEM SHENANDOAH	SILICICLASTIC
0.96	134-00347	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	BW0236	39.XXXX	-78.XXXX	M	OPEQUON/BACK CREEK	SILICICLASTIC
0.84	169-00129	STANLEY, TOWN OF	PWS	WELL	3836X007829X01	38.XXXX	-78.XXXX	M	SOUTH FORK SHENANDOAH	CONOCOCHIEAGUE

Appendix 5a: Reported groundwater withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons

M = Measured, E = Estimated. XX = data withheld for security purposes. (Table cont'd next page).

2007 Ground Water Use (MG)	DEQ Well Number	System Owner	Category	Source Type	MPID	Latitude (NAD83)	Longitude (NAD83)	Source Reporting Method	River Watershed	Geologic Unit
0.78	185-00087	JOHNS MANVILLE	MAN	WELL	385032078323501	38.8437550	-78.5423470	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
0.65	121-00002	BERTELSMANN ARVATO	MAN	WELL	390845077582701	39.1458330	-77.9741670	M	MAIN STEM SHENANDOAH	CONOCOCHIEAGUE
0.58	169-00126	STANLEY, TOWN OF	PWS	WELL	3833X07830X01	38.XXX	-78.XXX	M	SOUTH FORK SHENANDOAH	ROME, WAYNESBORO, SHADY, TOMSTOWN
0.36	182-00321	VALLEY PROTEINS INC	MAN	WELL	383210078500501	38.5361110	-78.8347220	M	NORTH FORK SHENANDOAH	EDINBURG, LINCOLNSHIRE, NEW MARKET
0.35	185-00157	AQUA VA - DIV OF AQUA AMERICA	PWS	WELL	AD2246	38.XXX	-78.XXX	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
0.13	185-00599	O-N MINERALS COMPANY	MAN	WELL	390112078200401	39.0198930	-78.3323570	E	NORTH FORK SHENANDOAH	BEEKMANTOWN
0.10	169-00270	STANLEY, TOWN OF	PWS	WELL	3834X07830X01	38.XXX	-78.XXX	M	SOUTH FORK SHENANDOAH	ROME, WAYNESBORO, SHADY, TOMSTOWN
0.04	185-00723	O-N MINERALS COMPANY	MAN	WELL	390100078200201	39.0176040	-78.3367430	E	NORTH FORK SHENANDOAH	BEEKMANTOWN
0.03	185-00032	BOWMAN APPLE PRODUCTS CO INC	MAN	WELL	384602078371901	38.7671330	-78.6215200	M	NORTH FORK SHENANDOAH	CONOCOCHIEAGUE
0.01	182-00585	MATHIAS BROTHERS INC	IRR	SPRING	383812078432101	38.6358060	-78.7222960	M	NORTH FORK SHENANDOAH	BEEKMANTOWN
0.01	134-00201	VALLEY PROTEINS INC	MAN	WELL	391338078144301	39.2275390	-78.2379300	E	OPEQUON/BACK CREEK	SILICICLASTIC
0.01	107-01472	AUGUSTA COUNTY SERVICE AUTH	PWS	WELL	3812X07913X01	38.XXX	-79.XXX	M	MIDDLE RIVER/CHRISTIANS CREEK	SILICICLASTIC

Appendix 5a: Reported groundwater withdrawals in the Shenandoah Valley in 2007. MG = Million Gallons
M = Measured, E = Estimated. XX = data withheld for security purposes. (Table cont'd from previous page).

DEQ Permit #	Facility Name	2007 Estimated Withdrawal (MG)	1Q Ave Daily (MGD)	2Q Ave Daily (MGD)	3Q Ave Daily (MGD)	4Q Ave Daily (MGD)	Source	Latitude (NAD83)	Longitude (NAD 83)	Reporting Method	Watershed	Geologic Unit
VAG840024	O-N MINERALS CHEMSTONE - Clear Brook	463.95	1.68	1.68	1.68	0.06	1,2,4	39.250917	-78.091042	E	Opequon/Back Creek	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840027	O-N MINERALS CHEMSTONE - Strasburg	393.24	1.44	1.44	1.44	0.00	1,2,4,5	39.020118	-78.323417	E	North Fork	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840030	STAUNTON LIME / BELMONT QUARRY	15.52	0.04	0.04	0.02	0.07	1,2	38.146513	-79.056071	E	Middle River / Christians Creek	BEEKMANTOWN
VAG840031	FRAZIER QUARRY - WATERMAN QUARRY	157.68	0.43	0.43	0.43	0.43	1	38.457555	-78.884715	E	North/Dry River	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840032	FRAZIER QUARRY - NORTH	157.68	0.43	0.43	0.43	0.43	1	38.509737	-78.857429	E	North Fork	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840035	TCS MATERIALS - ELKTON QUARRY	87.60	0.24	0.24	0.24	0.24	1	38.453942	-78.646506	E	South Fork	BEEKMANTOWN
VAG840039	VULCAN CONSTRUCTION MATERIAL - AUGUSTA	83.95	0.23	0.23	0.23	0.23	1	38.218927	-79.099951	E	Middle River / Christians Creek	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840040	SOUTH RIVER STONE - STUARTS DRAFT	287.10	3.19	0.00	0.00	0.00	1,2	37.989450	-79.084947	E	South River	ROME, WAYNESBORO, SHADY, TOMSTOWN
VAG840042	O-N MINERALS CHEMSTONE - Middletown	112.55	0.39	0.26	0.39	0.20	1	39.038173	-78.305194	E	North Fork	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840043	ROCKYDALE - FLATROCK QUARRY	55.26	0.08	0.05	0.17	0.30	1	38.703374	-78.740861	E	North Fork	EDINBURG, LINCOLNSHIRE, NEW MARKET
VAG840070	ESSROCK ITALCEMENTI GROUP	531.02	1.58	1.26	1.38	1.60	1	38.947122	-78.190381	E	North Fork	BEEKMANTOWN
VAG840133	ROCKYDALE - BROADWAY QUARRY	194.11	0.83	0.64	0.43	0.23	1	38.604400	-78.884842	E	North Fork	CONOCOCHIEAGUE
VAG840136	STUART M PERRY - BERRYVILLE	94.04	0.34	0.00	0.34	0.34	1,2	39.126895	-77.915658	E	Main Stem Shenandoah River	ROME, WAYNESBORO, SHADY, TOMSTOWN
VAG840142	STUART M PERRY - WINCHESTER	36.14	0.10	0.10	0.10	0.10	1,2	39.184845	-78.221124	E	Opequon/Back Creek	CONOCOCHIEAGUE

Appendix 5b: Estimated groundwater withdrawals due to surface mine dewatering in the Shenandoah Valley in 2007. MG = Million Gallons
E = Estimated. (1 – Mine pit dewatering, 2 – storm water, 4 – groundwater infiltration, 5 – vehicle equipment washing wastewater).